INSULATED TEST ROAD — STATE ROAD 26

JULY 1968

NO. 12

Joint Highway Research Project

by

R.P. STULGIS

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Progress Report

INSULATED TEST ROAD

STATE ROAD 26

TO: G. A. Leonards, Director
Joint Highway Research Project

July 1, 1968

File: 6-10-6

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-16F

A progress report "Insulated Test Road ... State Road 26" by Richard P. Stulgis, Graduate Assistant in Research on our staff, is presented to the Board for acceptance. This research was directed by Professor C. W. Lovell, Jr. of our staff.

A plan has been developed for the construction of a thermally insulated test road situated on a relocation of State Road 26, just west of the town of Rossville. The proposed installation has three sections (two insulated and one conventional design for control); each section being 200 feet in length. The foamed plastic thermal insulation is to be used in a 1-inch thickness at the base of a normal section, and in a $1\frac{1}{2}$-inch thickness in a reduced-thickness section. The relative effectiveness of the insulation in preventing frost penetration through the pavement sections will be evaluated by monitoring 105 subsurface thermistors. Surface deflection measurements are also recommended.

This report is in fulfillment of a study proposal approved by the Board on September 27, 1967. The test road is planned for construction before the Winter of 1968-69. Detailed plans for collecting data and evaluating performance are to be worked out jointly by selected personnel of the Research and Training Center and the Joint Highway Research Project, and several additional reports to the Board are anticipated over the next several years.

Respectfully submitted,

Harold L. Michael
Associate Director

HLM:ms

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Progress Report

INSULATED TEST ROAD

STATE ROAD 26

by

Richard P. Stulgis

Graduate Assistant in Research

Joint Highway Research Project

File No: 6-10-6

Project No: C-36-16F

Purdue University

Lafayette, Indiana

July 1, 1968

ACKNOWLEDGEMENTS

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Financial assistance which made this study possible was provided by the Joint Highway Research Project between the Indiana State Highway Commission and Purdue University; Director G. A. Leonards.

The writer also wishes to express sincere thanks to the following persons for the assistance which they rendered: Dr. M. E. Harr, Professor of Soil Mechanics, Purdue University, for his suggestions and guidance; Mr. Wayne G. Williams, the Dow Chemical Co., Midland, Michigan, for his generous help and suggestions pertaining to the design, instrumentation and construction of the test installation; Mr. Da-Min Ho, Graduate Assistant in Soil Mechanics, Purdue University, for his help in the development of the thermal design of the installation; Mr. W. T. Spencer, Head of the Bureau of Materials and Tests, Indiana State Highway Commission, for his help in determining the location for the test installation; and Mr. H. R. J. Walsh, Director, Research and Training Center, Indiana State Highway Commission, for his advice on the thermal instrumentation for the project.

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ABSTRACT

The requisite planning for an experimental section of Indiana highway, incorporating foam-plastic insulating layers to attenuate frost penetration, was developed.

With the help of Indiana state highway officials, a flexible pavement construction project (Project No. S271) on State Road 26 was selected, within which the proposed field installation would be located. Two insulated sections and one non-insulated section comprise the test installation.

Selection of the insulation thicknesses to be used was based on the results of a computer analysis developed at Purdue University. This program, under the condition of one-dimensional heat flow by conduction, predicts the distribution of temperature with time throughout a layered medium. Input data utilized were based on climatic records for the area in which the site is located and on estimated thermal properties of the component layers of the proposed highway cross-section.

Methods of evaluating the thermal and structural performance of the insulated and non-insulated sections were recommended. Thermal performance is to be evaluated by means of thermistors strategically placed in each of the three sections and structural performance by means of Benkelman beam tests.

Special construction procedures were recommended for the field installation, due to the experimental nature of the project.

INTRODUCTION

The use of a thermal barrier beneath a transportation route, in order to minimize frost damage, has received a recent impetus with the availability of foamed plastics which are excellent insulators.

Research and development effort over the past decade has shown that the use of such materials is technologically feasible and that such use can be economically desirable. As market applications increase, improvements in the foamed plastic properties and in the technology of its placement can be expected ... as well as some reduction in its as-placed cost.

A number of highway departments are in the process of gaining first hand experience with the insulated design concept by means of test roads. This is probably a necessary step for each department, since soils, loads, environment and service requirements vary considerably with and within the various political units.

PURPOSE

The purpose of the study was to develop the requisite planning for an experimental section of Indiana highway incorporating foam-plastic insulating layers, including appropriate testing and evaluating procedures.

Although field test installations have already been made in the northern United States, Canada, and in Europe, and have demonstrated good performance, the Indiana installation has two definite objectives. The first is to obtain first-hand experience with insulated construction and performance of the insulated design. Secondly, the rather complete instrumentation of the project will permit both validation and extension of extant analytical models for thermal pavement design.

LOCATION AND DESCRIPTION OF FIELD TEST INSTALLATION

The proposed experimental test section of roadway will be constructed in a cut area located within the 3.1 mile length of flexible pavement construction proposed on State Road 26 (S-Project No. 271). As shown on the project locus (Figure 1), this construction job is located in northwestern Clinton County near Rossville, Indiana.

The project lies in the north central portion of the Tipton Till Plain Physiographic Subsection of Indiana (27).[1] Rolling and hilly topographic features found in the project area are attributed to the proximity of a segment of the Bloomington Morainic system which is located to the south of State Road 26 in an east and west direction. An exploratory program, consisting of hand-borings, carried out by the Division of Materials & Tests of the Indiana State Highway Commission (11) found the subgrade soils in the vicinity of the test installation to be of the A-6 group (AASHO Classification). The textural classification of these soils ranges from silty clay to clay and thus a frost susceptible soil appears to comprise the subgrade, at least to the depths to which the hand borings were carried.

This location was selected on the basis of the following factors:

(1) Anticipated subgrade soils in this area are classified as F4 (Corps of Engineers Classification System), which is highly frost susceptible.

(2) The most severe test for the insulation would be in a cut area where the soil would have easier access to water. The proposed construction in this location would entail cuts of from one to five feet.

1. Numerals underlined in parentheses refer to entries in the Bibliography, page 51.

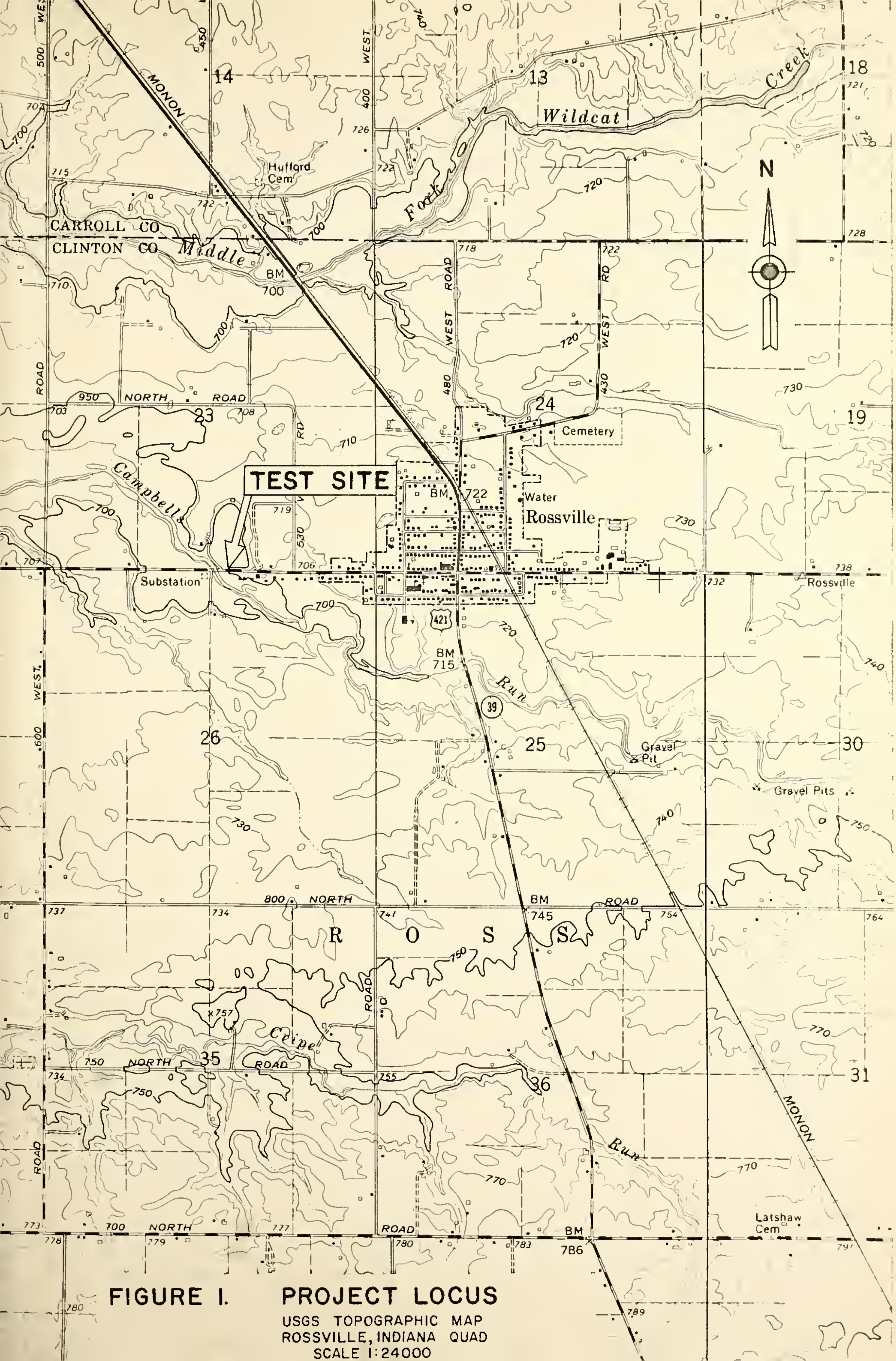


FIGURE I. PROJECT LOCUS
USGS TOPOGRAPHIC MAP
ROSSVILLE, INDIANA QUAD
SCALE 1:24000

(3) The road is currently posted as "Rough Pavement" and it has been determined that this deterioration is, in part, caused by frost action.

(4) The location is close to Lafayette, which will facilitate trips to the site to retrieve data.

(5) Construction of the test installation will begin in the Summer of 1968.

As shown on the plan (Figure 2), the experimental roadway will be constructed between Station 100 + 00 and Station 106 + 00 of the contract section. The test area will be divided into two test sections and one control section, each 200 feet in length. The test sections are designated "A" and "B". Section "A" will include a one inch thick insulating layer and Section "B" will include a one and one half inch thick insulating layer, the insulating layer in both cases being placed on the subgrade. The depth of this layer below finished grade will be 20 inches in Section "A" (which will utilize the normal pavement section for the project) and 14 inches in Section "B" (which will eliminate the six inch subbase layer). The width of the insulating layer will be 34 feet in Section "A" and 46 feet in Section "B". The control section, utilizing the normal design for the project, will be located between the two test sections and is designated Section "C". Transitions between the insulated sections and the control and normal roadway sections will have to be provided, due to differences in subgrade elevations between these sections. Recommended transitions are as shown in Figure 3. Vertical strings of thermistors will be installed throughout the cross section at the center of each of the three sections, transverse to the roadway center line.

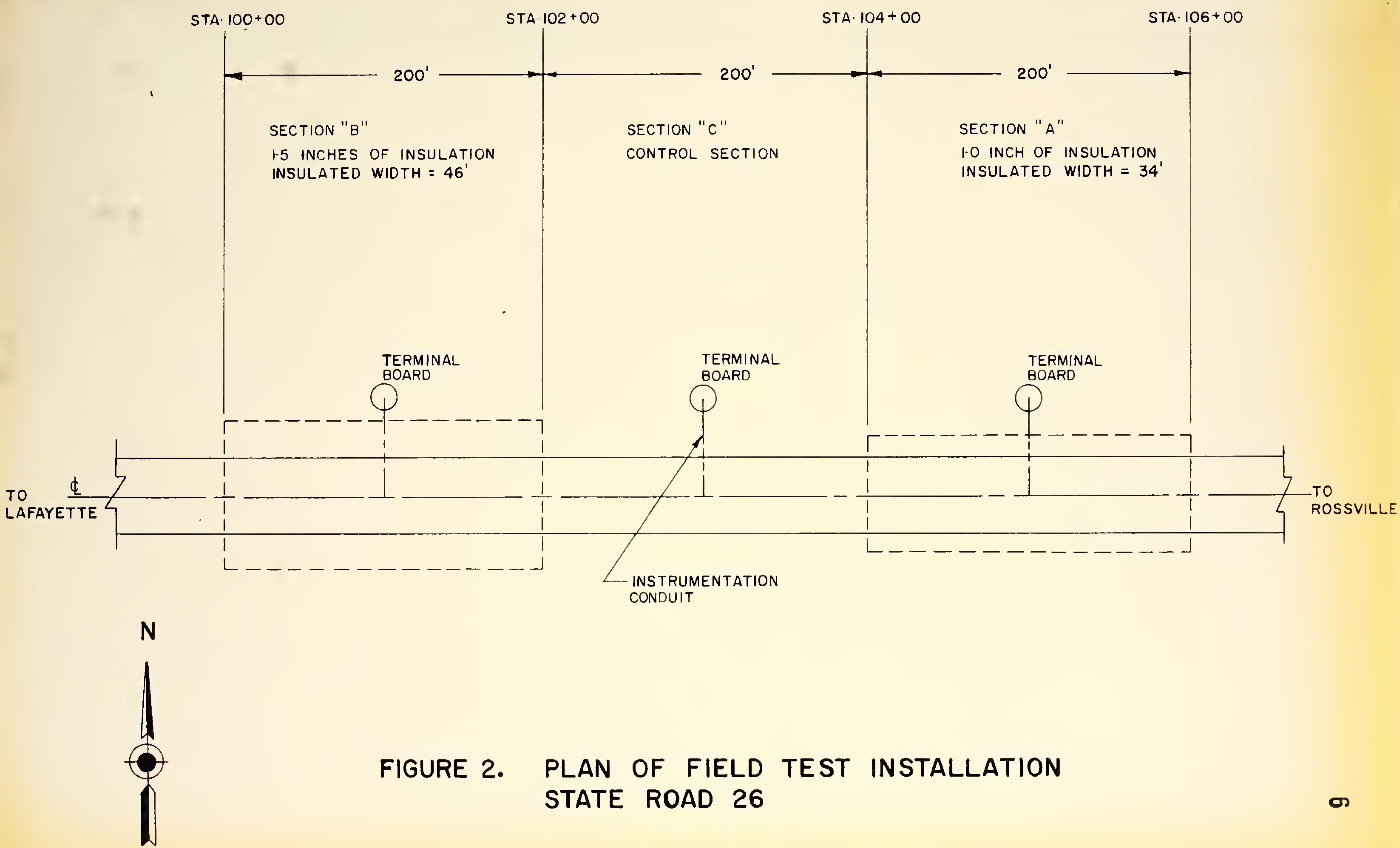
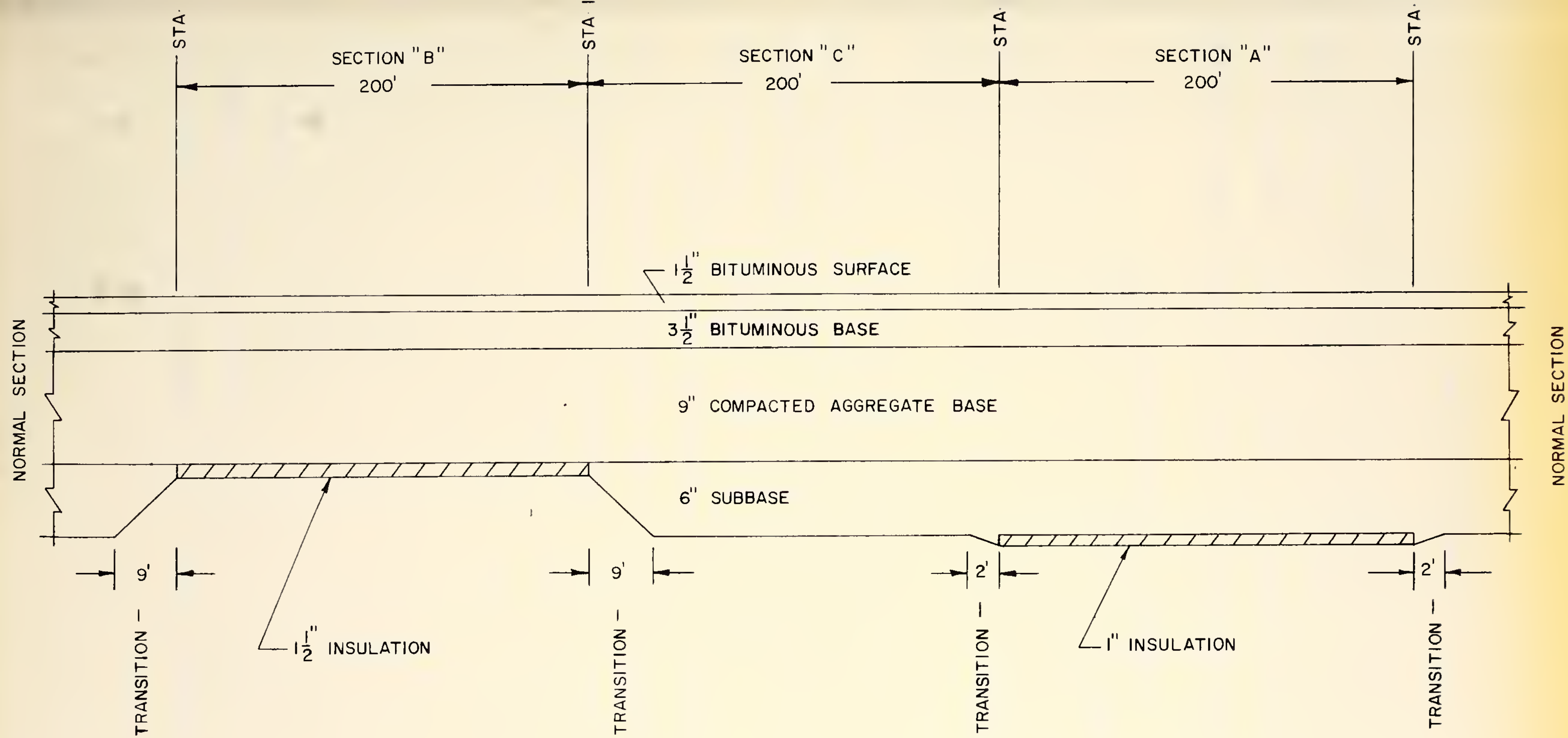


FIGURE 2. PLAN OF FIELD TEST INSTALLATION STATE ROAD 26

NOT TO SCALE



NOTE: ALL TRANSITIONS AT $\frac{1}{2}$" PER FT.

FIGURE 3. SCHEMATIC BASE PROFILE

NOT TO SCALE

DESIGN PROCEDURE

The design of the field test installation consisted of determining the number, type and length of pavement sections, the thickness and depth of the insulating layer, the width of the insulation, the location of temperature sensing elements, and other subordinate details.

Number, Type and Length of Sections

It is recommended that the installation be comprised of three parts, two insulated sections (one utilizing the normal pavement section and the other eliminating the six inch subbase layer) and one control or normal design section.

Section "A" affords a direct comparison between the performance of equal thicknesses of an insulated section and a non-insulated section (Control Section). Section "B" is reduced in thickness relative to the normal section by omission of the six inch subbase.

The insulation serves two purposes: (1) It prevents frost penetration into frost susceptible subgrade soils, thereby preventing frost heaving and weakening of the pavement upon thawing; and (2) by avoiding a reduced strength condition in the subgrade, a thinner pavement may be used. The cost of the insulation (placed) must be offset by savings in aggregate and/or improved pavement performance, in order to make the insulation method economically competitive with conventional methods. Section "B" is intended to demonstrate the reduction-in-thickness concept, although it is unlikely that said reduction is sufficient to produce a net saving in construction cost. In reducing the pavement thickness, however, two questions arose. The first concerned the structural adequacy of the reduced

thickness pavement section, and the second, the stress level transferred to the insulating layer due to wheel loads. A CBR method of analysis (39), for the anticipated soil and loading conditions, attested to the structural adequacy of the reduced section. With respect to the second question, advice was sought from a representative of the major manufacturer of highway insulation (36). Previous experience indicates a minimum flexible pavement section consisting of three inches of bituminous material and twelve inches of granular base will hold the vertical stress on the insulation to a desired limit of 15 psi. The proposed Section "B" is three inches deficient with respect to the twelve inch gravel minimum but exceeds the lower limit of three inches of bituminous material by two inches. It was concluded that the reduced section would provide the minimum protection desirable with respect to the stress level transferred to the insulating layer.

Test sections must be long enough to relegate end effects to a minor role. Figure 4 compares the thermal conditions which would exist in a continuous section with those of a relatively short test section.

Based on previous research (30), a test section 50 feet long is adequate for thermal evaluations. However, longer sections are required for pavement performance ratings. Therefore, within this framework and the practical constraints of the project, a length of 200 feet was chosen for each section. Also, a total project length of 600 feet allows the entire installation to be contained within a single continuous cut, which is slightly greater than 600 feet in length. Thus, non-uniformity of subgrade soil conditions, is held to a practical minimum.

It should also be pointed out that normal construction procedure in this cut could involve a subgrade treatment of undercutting, removal and

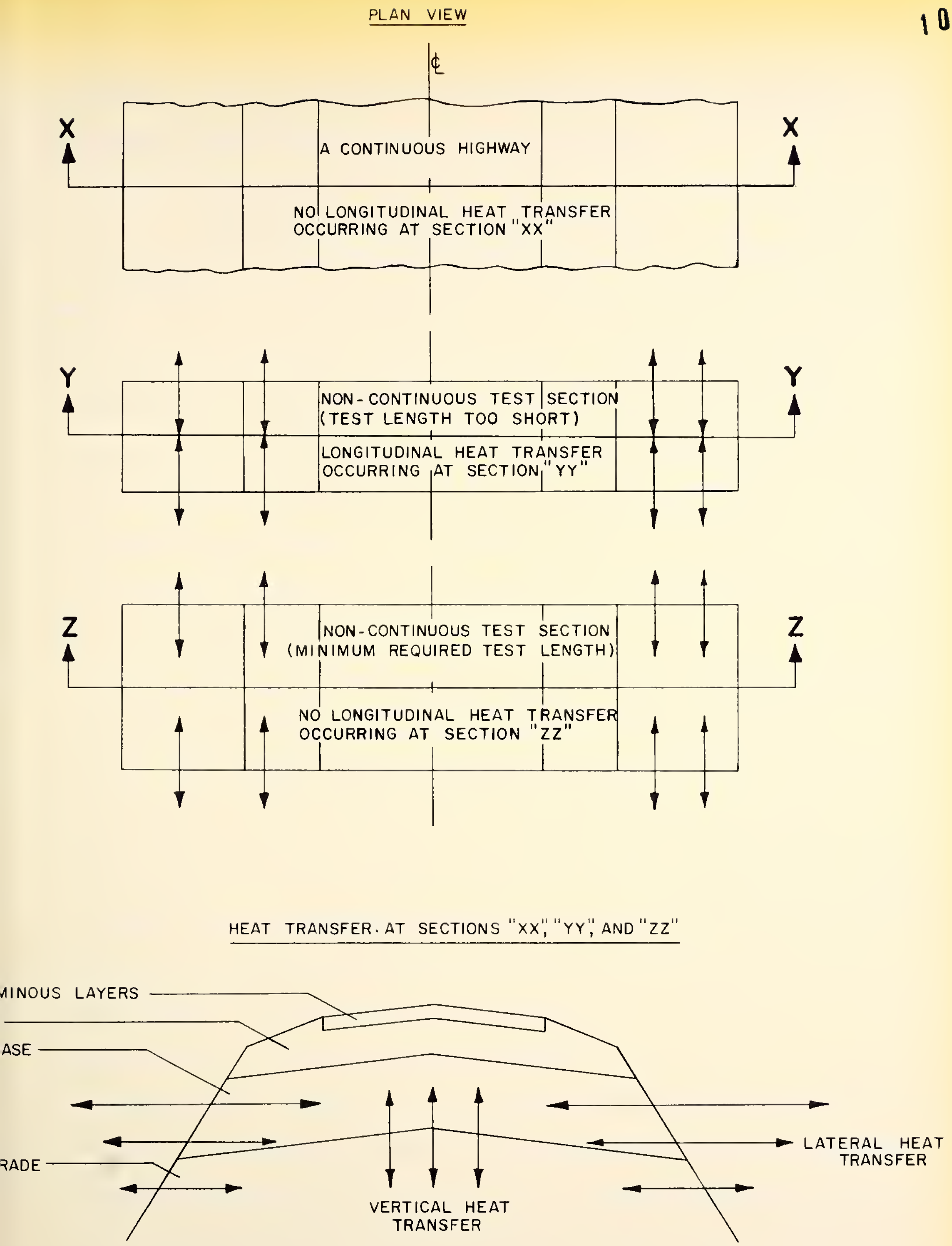


FIGURE 4. COMPARISON OF THERMAL CONDITIONS EXISTING IN AN ACTUAL HIGHWAY AND A NON-CONTINUOUS TEST SECTION

replacement of certain frost susceptible subgrade material, indicating an additional economic factor in favor of the insulation.

Thickness and Depth of Insulating Layer

The insulating layer should be placed directly on the subgrade. If granular materials are placed between the insulating layer and the subgrade, heat losses in the lateral direction increase. Conversely, placing the insulating layer on a subgrade which has a relatively high heat capacity, reduces heat losses in the lateral direction and one-dimensional heat flow is apt to constitute a reasonable model of the actual phenomenon. Placing the insulating layer "deep" in the pavement section is desirable not only from the thermal standpoint, but also structurally, since stresses on this layer are minimized (4).

To estimate the thickness of insulation required in the test sections, a computerized solution, developed principally at Purdue University, was used (9). This program, under the condition of one-dimensional heat flow by conduction, predicts the distribution of temperatures throughout a layered medium with time, by means of a finite difference technique. There are essentially no limitations on the functional form of initial and boundary conditions, or on the variation of physical and thermal properties of the layered system. Pertinent parts of the program and an example of its application to Section "A" are included in Appendix A.

The predictive capability of the program is tempered by the quality of the input, which includes the dimensions of the cross section, the physical (and thermal) properties of the layers, the air-surface transfer factor, an air temperature-time function, temperature versus time at a relatively

great depth, and an initial temperature-depth function. See Figure 27 of Appendix A. The procedures used in selecting the various input data and, where applicable, an assessment of the effect of the chosen values on the predicted temperature distribution with time, are described below, with specific reference to Section "A".

Dimensions of the Cross Section. The starting point is the normal design section. A value judgement is made relative to position and thickness of the insulation layer and a reduction in thickness of granular material in the normal section. Having done this, the components of the pavement section are further subdivided into any number of incremental thicknesses desired. The variation of temperature with time at the center of these increments is computed. For example, in Figure 27, selection of increments five and seven will yield the temperature one inch above and one inch below the insulation. By repeating the sequence of data cards, several problems can be run in one batch and thus, several thicknesses of insulation may be investigated at one time. A thermally acceptible section is one which essentially prevents penetration of the 32^{o}F isotherm through the insulation. Structural and economic factors must also be judged.

Physical (and Thermal) Properties for Each Layer. Values for the unit weight, initial water content, volumetric heat and thermal conductivity were selected for each of the component layers of the pavement section. Values for the bituminous surface and base, compacted aggregate base, and subbase were selected from values for similar materials used in the state of Maine's test installation. Values for the insulation were based on reported values for Styrofoam HI Plastic Foam, manufactured by The

Dow Chemical Company (8), while values for the subgrade were based on reported values for Crosby silty clay (17). With the exception of the insulation, the selected values are rather approximate. The predictions may be examined as to sensitivity to variation in any factor. For example, Figure 5 illustrates the effect of varying water content in the base.[1]

Air-Surface Transfer Factor. This factor attempts to relate pavement surface temperature to air temperature. This relation is complex, being influenced by transient local environmental conditions. It is expressed as a ratio of $\left(\frac{\text{pavement temperature}}{\text{air temperature}}\right)$. The ratio value assumed for this analysis is 0.99. Due to the fact that the pavement surface will generally exist at a temperature which is higher than the mean air temperature, the selection of 0.99 for the air-surface transfer factor is conservative.

Initial Conditions. In actuality, the computer solution generates a three-dimensional surface, on which any point represents a temperature at a given depth and time. From Figure 27, it can be surmised that although the upper and lower boundary conditions will greatly affect the shape of the surface generated, the initial conditions will affect the functional relationship only at short times, i.e., with time the effects of the initial conditions greatly diminish. Therefore, although it is desirable to predict the initial temperature distribution throughout the pavement section as close to the actual as practicable, the error associated with any reasonable assumption should not be significant. Thus, it was assumed that the initial temperature distribution was constant with depth, at a value of $50^{\circ}F$.

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1. Including a base course and a subbase course.

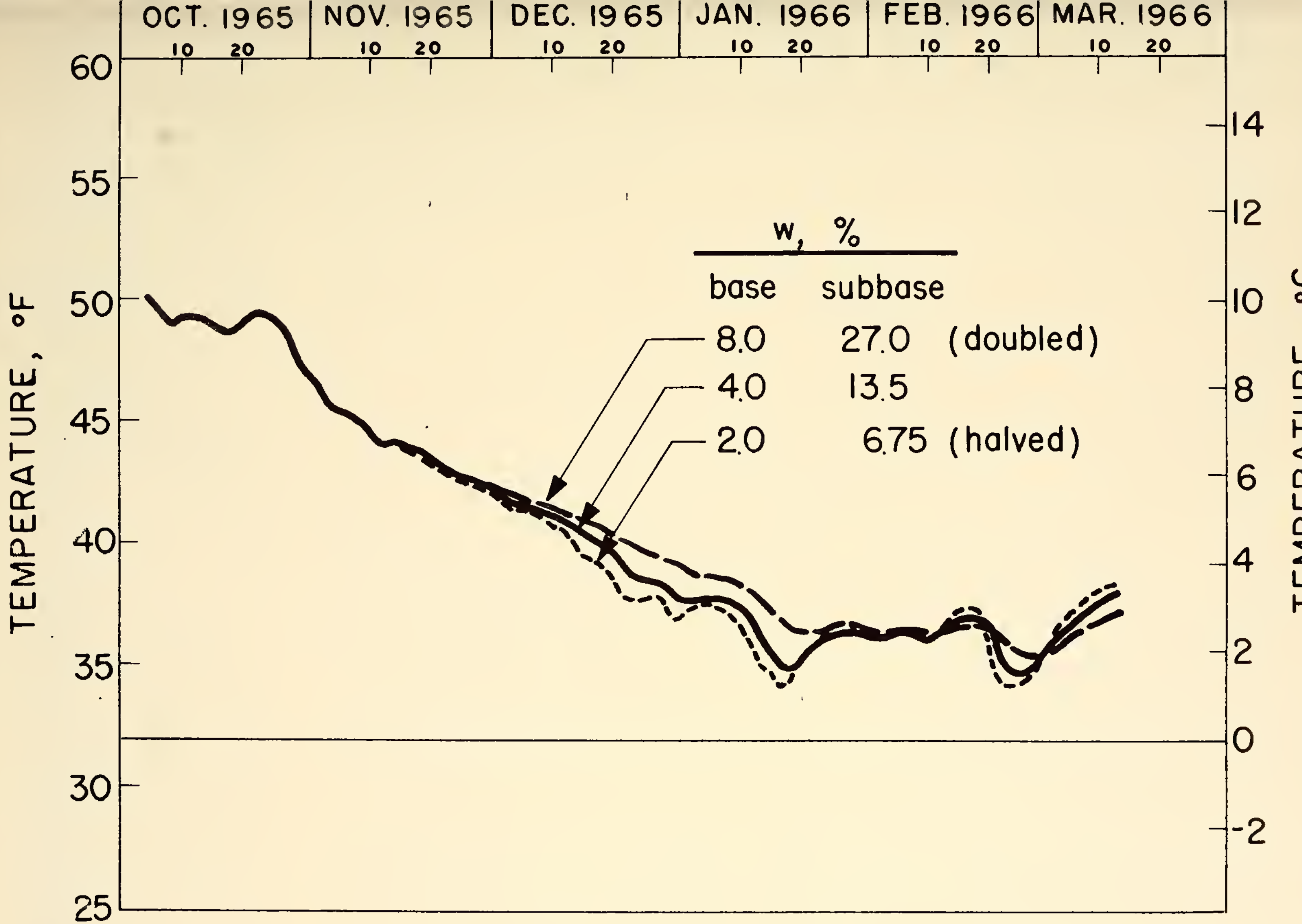


FIGURE 5. EFFECT OF VARYING WATER CONTENT IN BASE, TEMPERATURE AT 5 IN. BELOW INSULATION, MAINE TEST ROAD, SECTION B

(FROM 15)

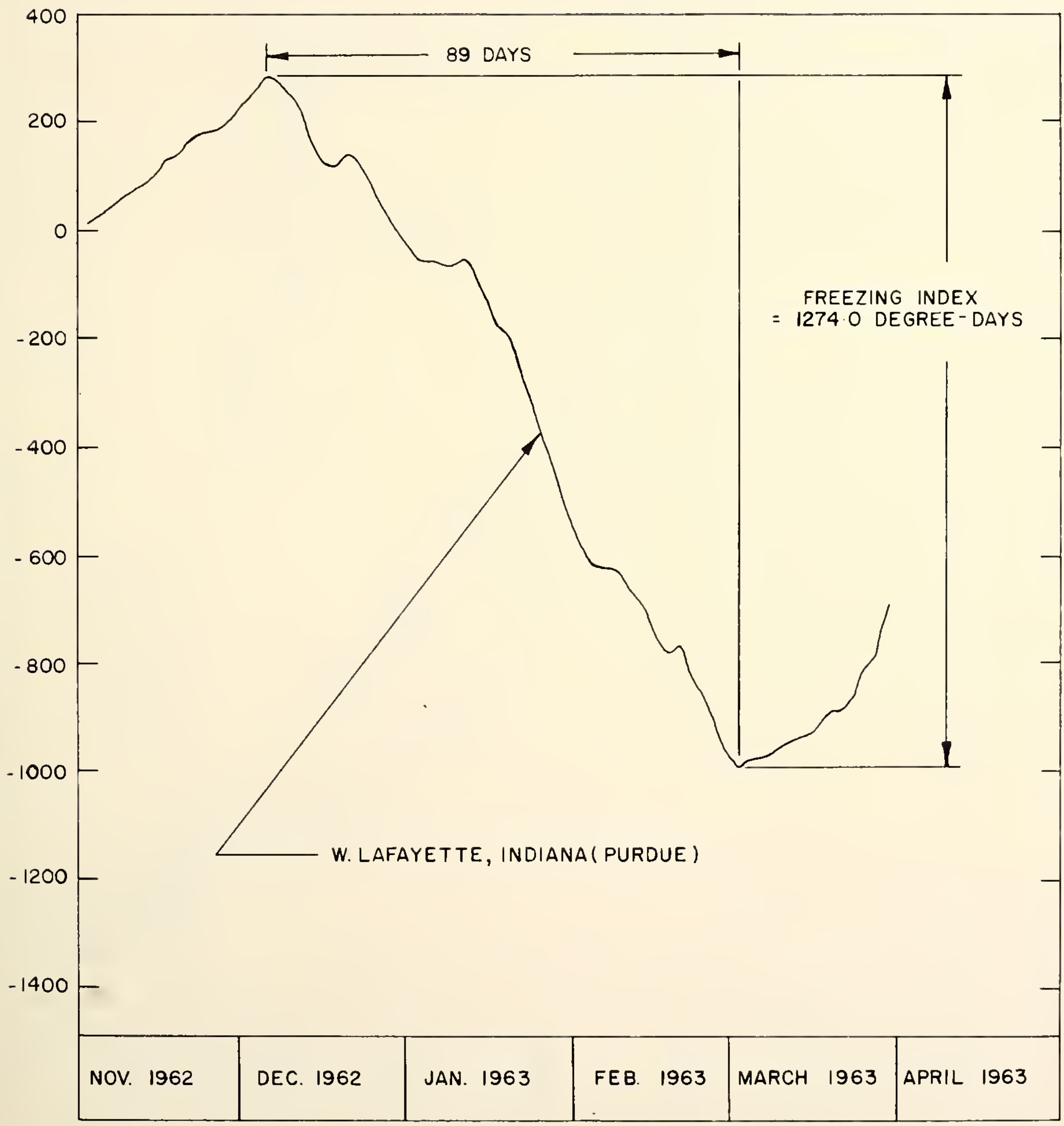
Upper Boundary Conditions. In the absence of air temperature data for the actual test site, the upper boundary condtions were determined from mean daily air temperature data taken at West Lafayette (Purdue University). It was decided to use the freezing index[1] as a measure of the severity of specific winters to aid in choosing, for design, the most severe winter. After collecting temperature data and computing values of freezing index for the winters of the past ten years, the Winter of 1962-1963 was selected as the most critical one, having a freezing index of 1274.0 degree-days. Figure 6 shows the curve of cumulative degree-days for the Winter of 1962-1963, and Appendix B contains the computer program used in computing the values of freezing index. Also included in Appendix B is the Output for the Winter of 1962-1963, from which the curve in Figure 6 was constructed.

The freezing index is an admittedly approximate way of selecting the critical upper boundary condition, although it is one that can be rather simply applied for any location of air temperature record. It is possible to have a deeper frost penetration with a slightly lower freezing index, if the duration of the freezing period is longer. However, in this analysis, the freezing index of the Winter of 1962-1963 was 400 degree-days greater than the winter with the next highest freezing index, the duration of the freezing period being about the same for both years. Accordingly, the selected value is probably a conservative one.

Lower Boundary Conditions. The influence of the lower boundary is illustrated by example in Figure 7. This condition is a difficult one accurately to assess, and the instrumentation recommended in this report should provide valuable

1. The freezing index is defined as the difference between the maximum and minimum point on the curve of cumulative degree-days, a degree-day representing one day with a mean air temperature one degree above or below freezing.

FIGURE 6. CUMULATIVE DEGREE-DAYS ABOVE AND BELOW 32°F AT W. LAFAYETTE (PURDUE)



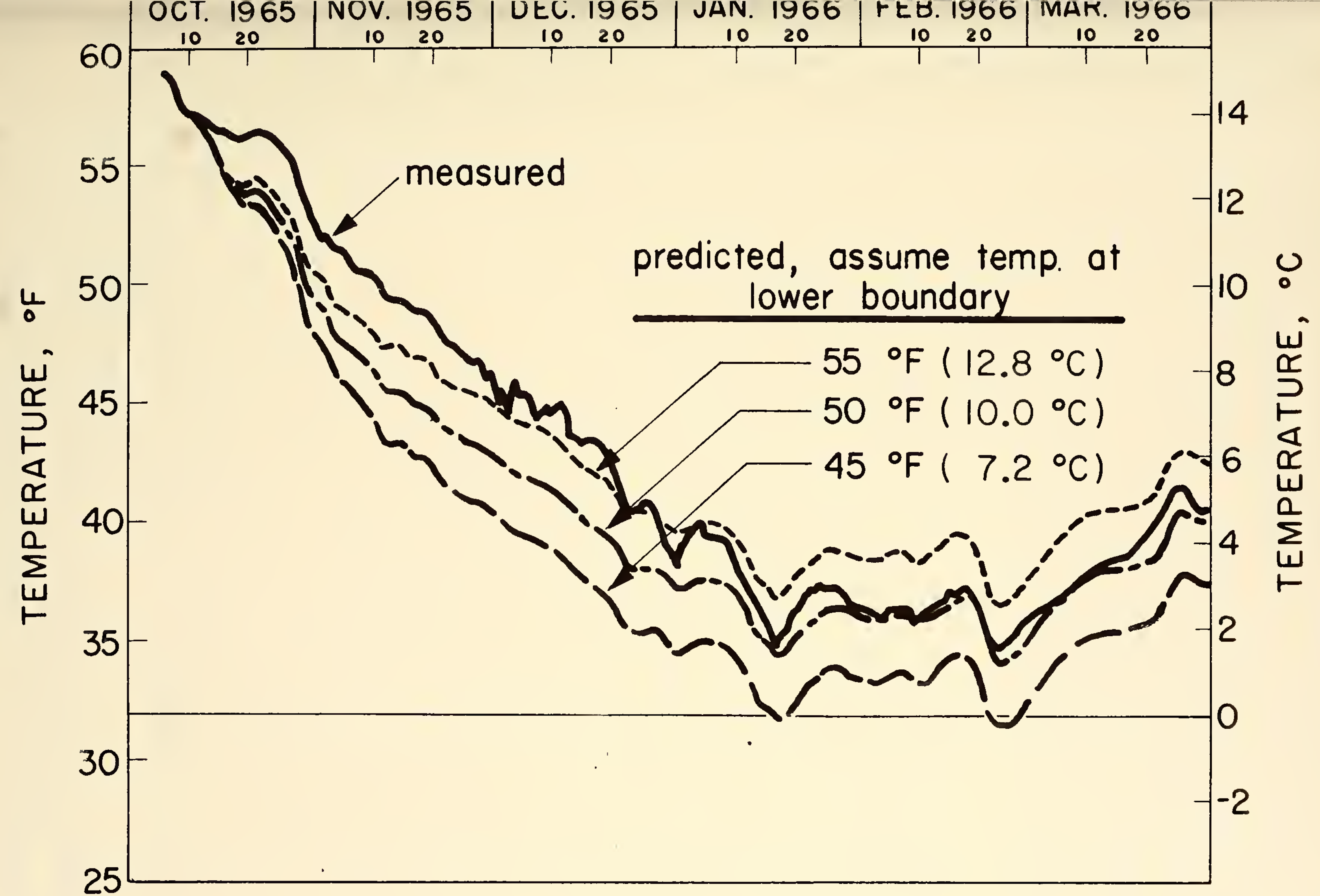


FIGURE 7. EFFECT OF VARYING LOWER BOUNDARY TEMPERATURE, TEMPERATURE AT 5 IN. BELOW INSULATION, MAINE TEST ROAD. (FROM 15)

insight with respect to it. For the purposes of this analysis, the lower boundary was taken as a constant temperature value of 50°F at a depth of eight feet below the roadway surface. A value of 56°F at a depth of 100 inches below the pavement surface was used for the lower boundary in predicting the performance of Maine's test installation (15), and correlation between the predicted and the actual values of temperature was quite good. Therefore, Indiana being located further south than Maine, it would appear that a value of 50°F is suitable.

Before presenting the results of the analysis, it should be pointed out that despite the error that can be introduced through the assumptions made in selecting input data, good correlation between predicted and actual temperature distributions, such as shown in Figures 8 and 9, can be obtained.

The results of the analysis performed for Sections "A" and "B" indicate that a thickness of one inch and one and one-half inches, respectively, will provide adequate thermal protection. Figures 10 and 11 depict the predicted temperature distribution with time, one inch above and below the insulation, for Sections "A" and "B", respectively. Figure 10 indicates that the temperature below the insulation in Section "A" may drop several degrees below freezing for a period of time. Figure 11 indicates a similar (but lesser) effect for Section "B". However, it is felt that the designs are thermally adequate for the following reasons: (1) the assumed upper boundary conditions are on the conservative side, (2) the assumed air-surface transfer factor is conservative, (3) the lower boundary condition may be on the conservative side, and (4) temperatures down to 28°F can be tolerated below the insulation for several days without damage (36).

A similar analysis was performed for the Control and the existing highway section, the results being shown on Figures 12 and 13, respectively.

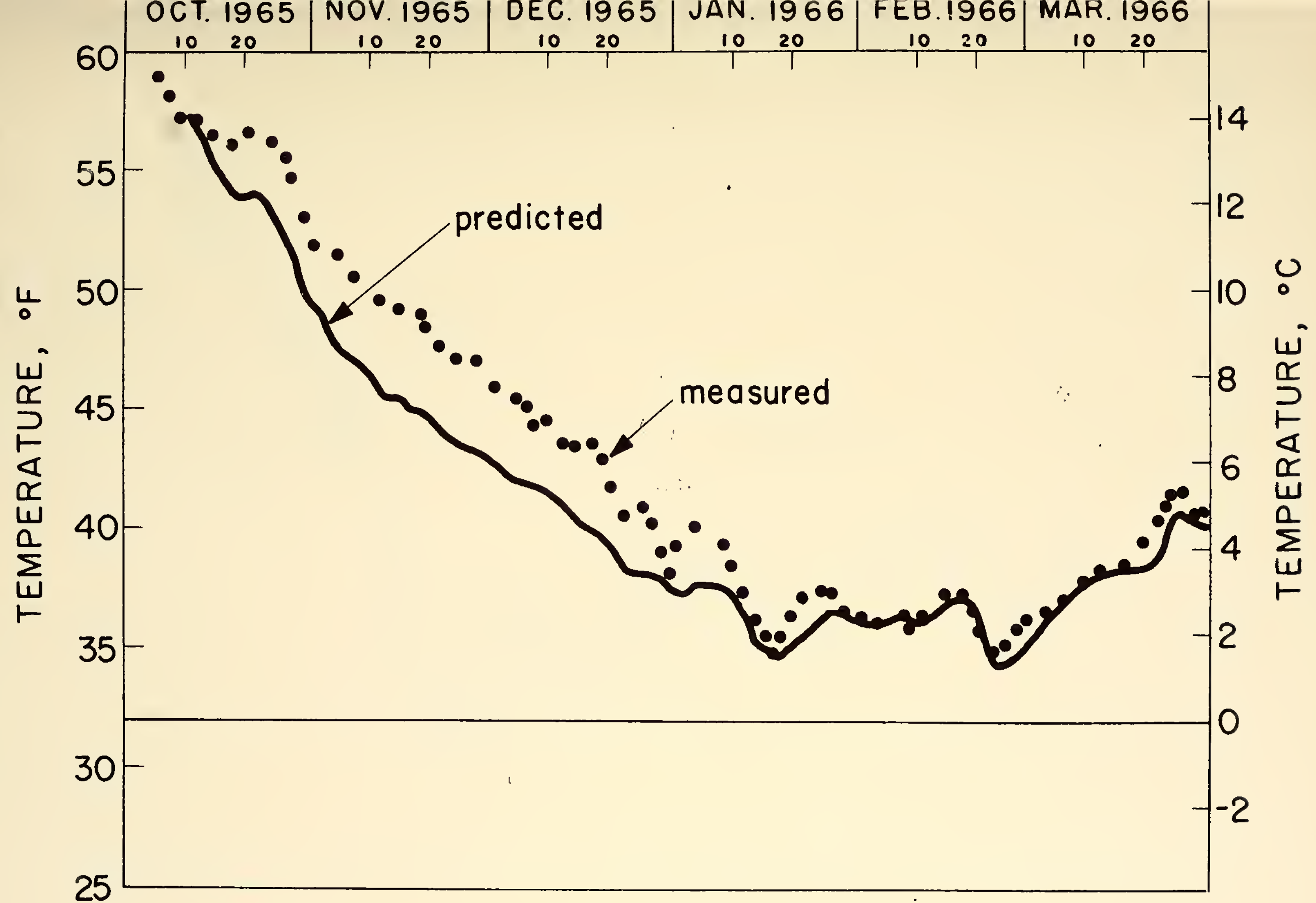


FIGURE 8. TEMPERATURE vs. TIME, 5 IN. BELOW INSULATION, MAINE TEST ROAD. (FROM 15)

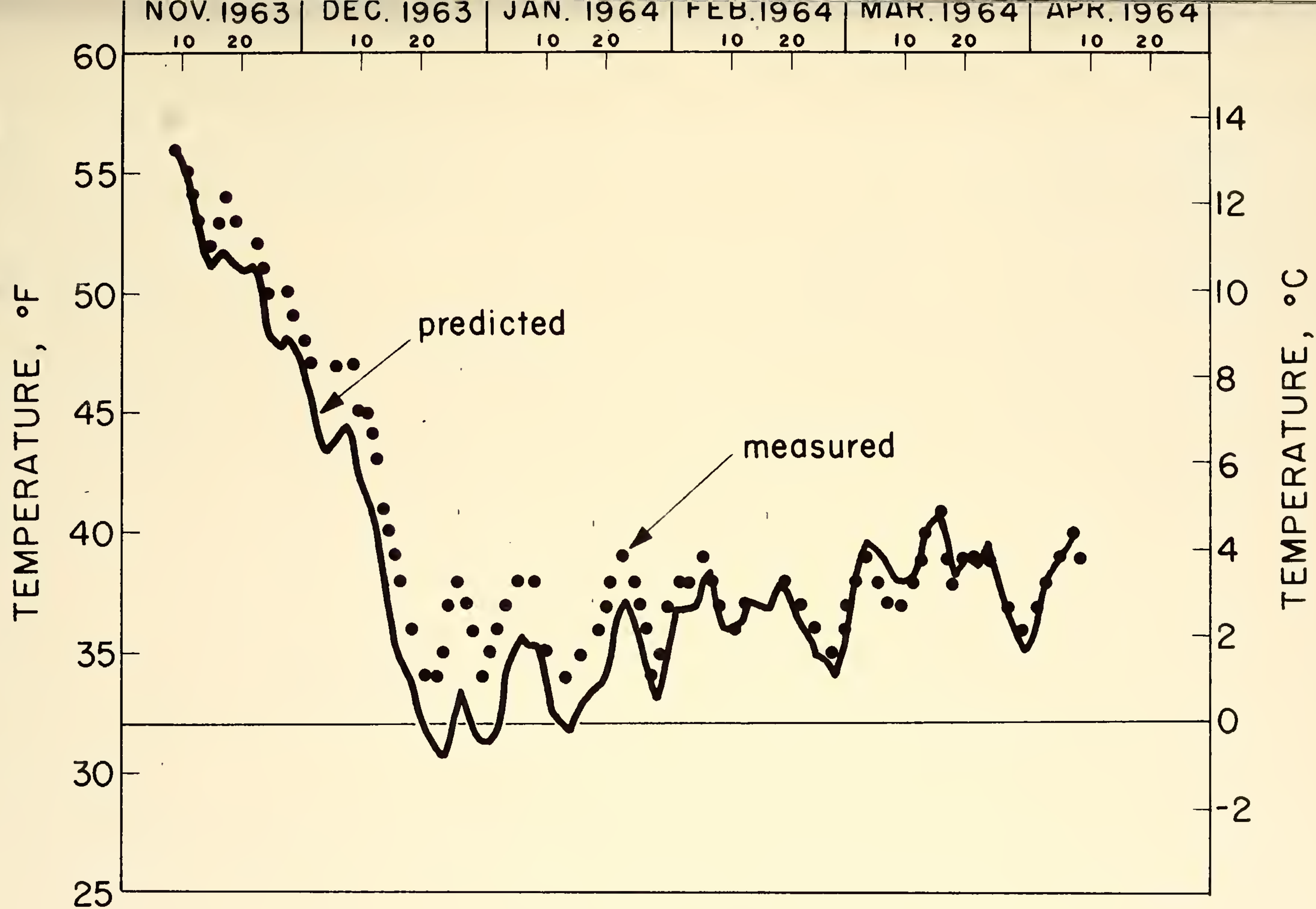


FIGURE 9. TEMPERATURE vs. TIME, 5 IN. BELOW INSULATION, IOWA TEST ROAD, 1963 - 1964 (FROM 15)

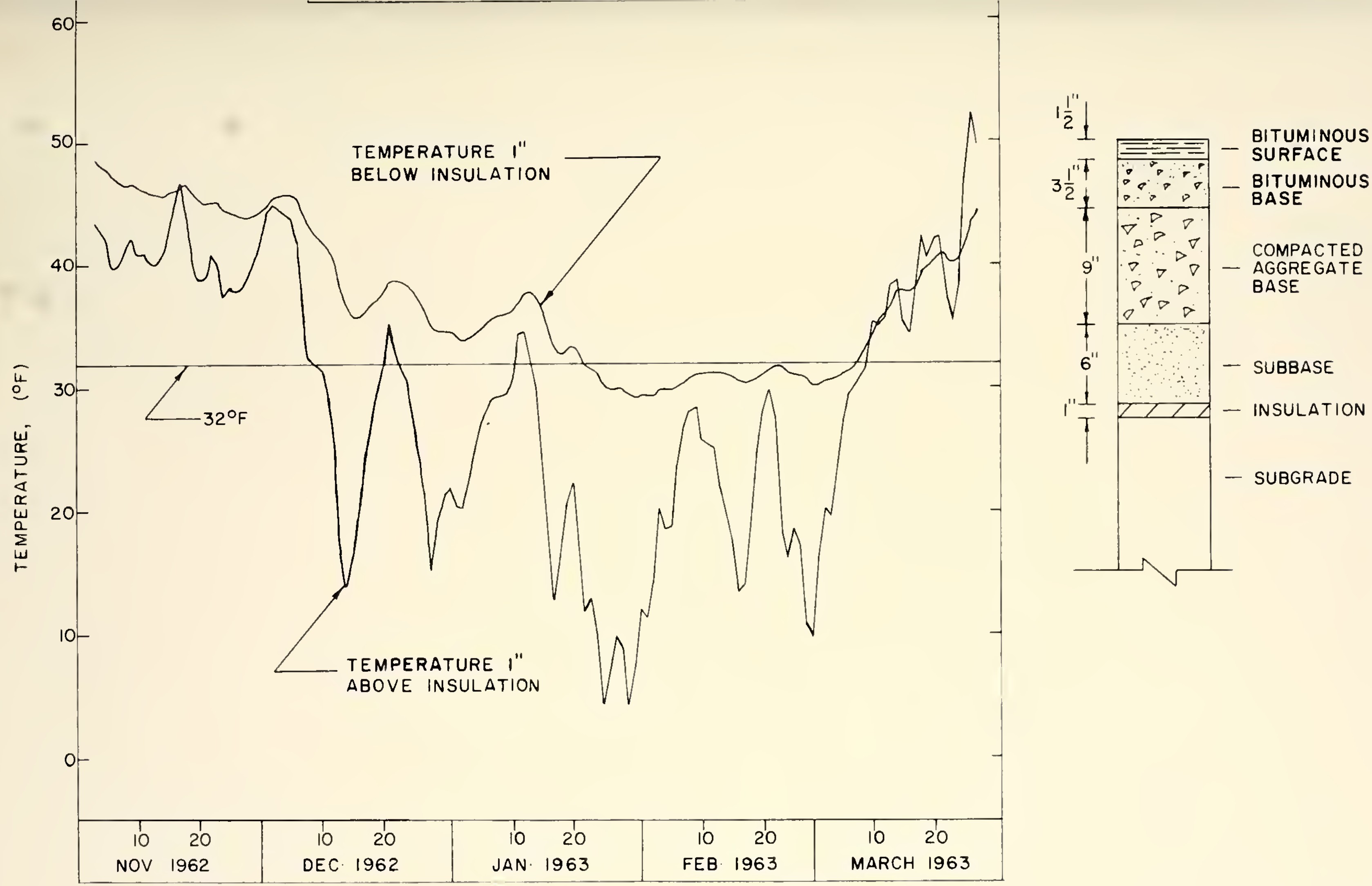


FIGURE 10. TIME vs. TEMPERATURE - SECTION "A"
(PREDICTED)

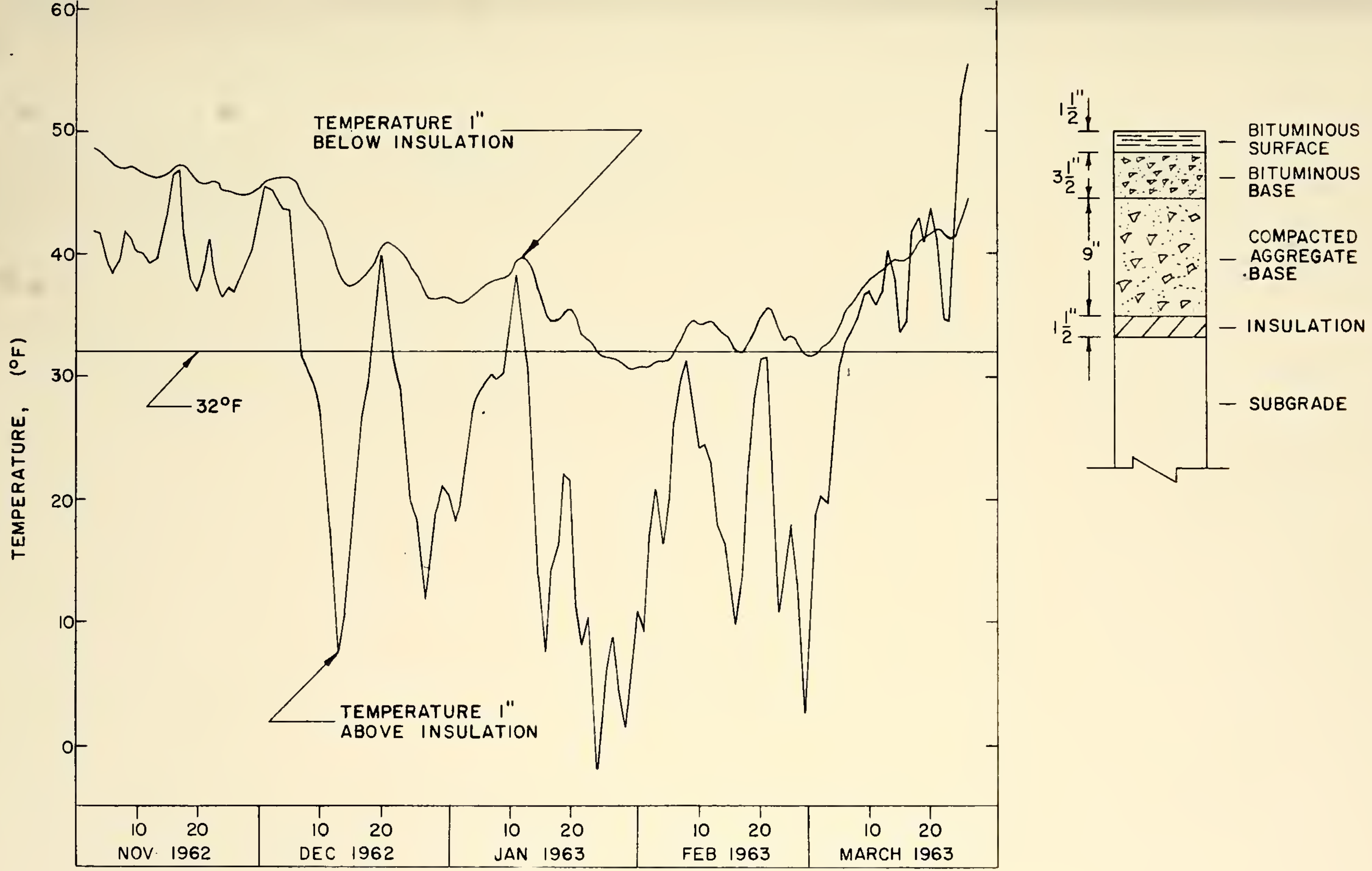


FIGURE II. TIME vs. TEMPERATURE - SECTION "B"
(PREDICTED)

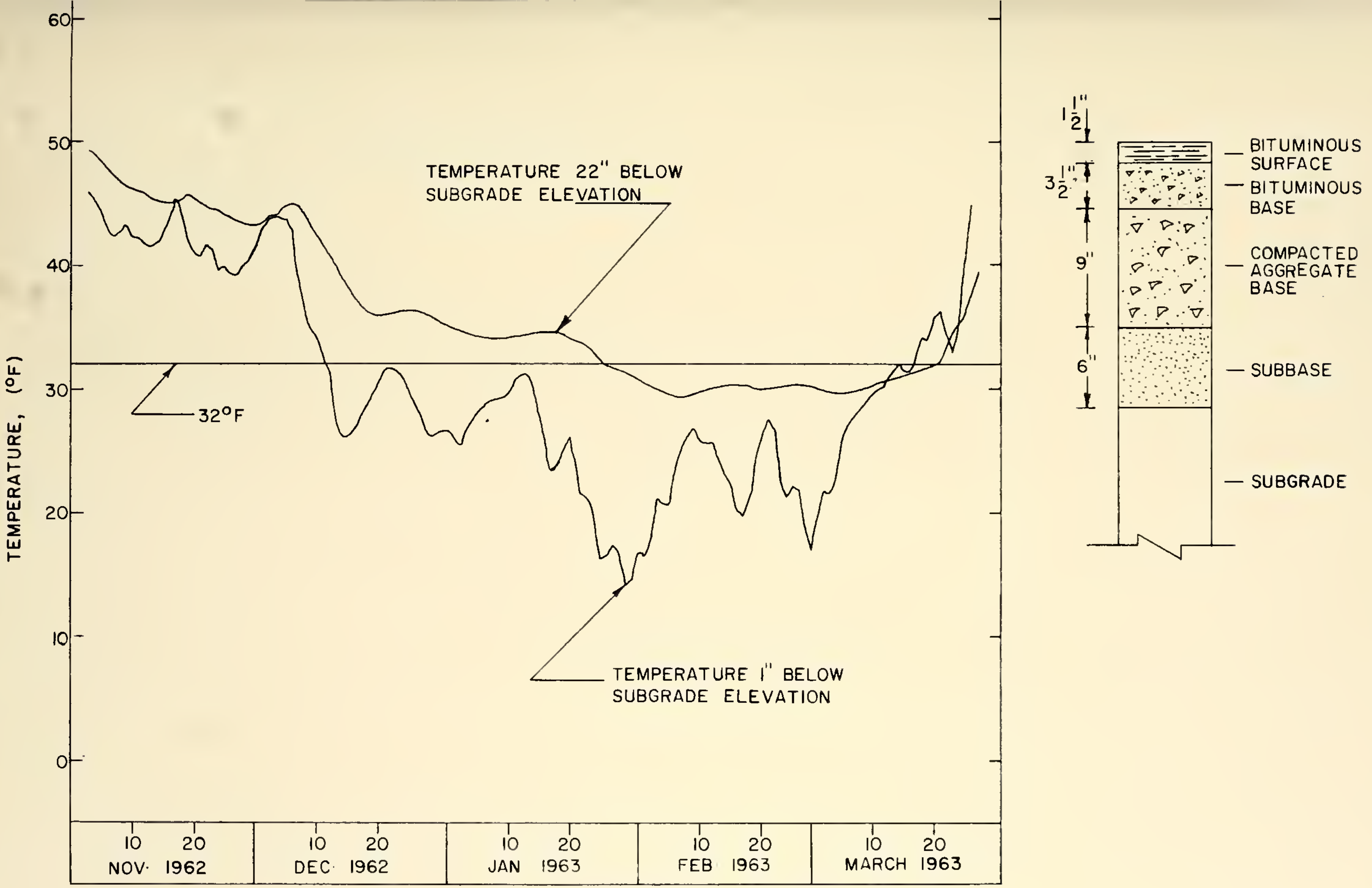


FIGURE 12. TIME vs. TEMPERATURE - CONTROL SECTION
(PREDICTED)

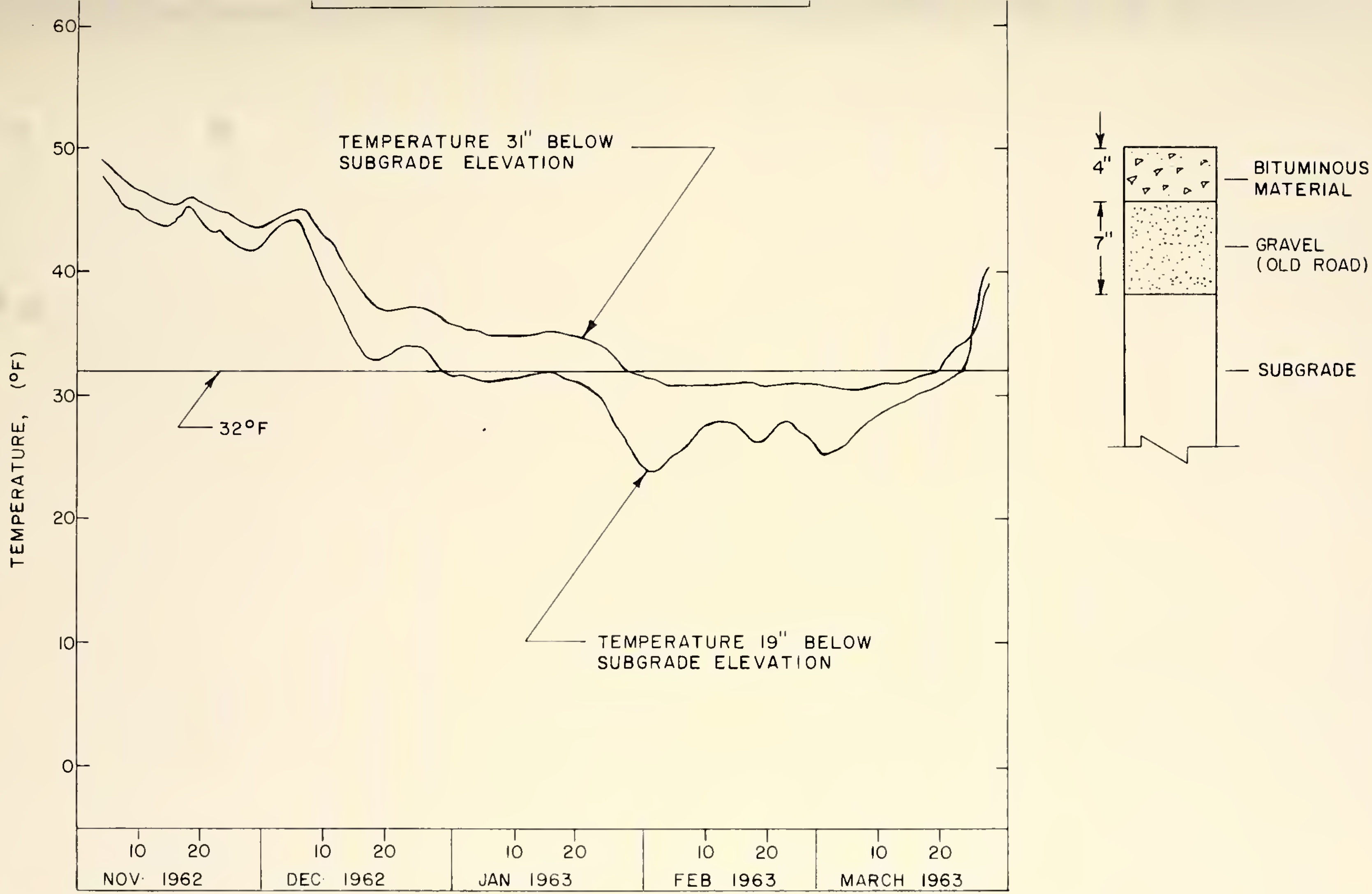


FIGURE 13. TIME vs. TEMPERATURE - EXISTING PAVEMENT SECTION
(PREDICTED)

Figure 12 indicates that frost penetration of almost two feet into the subgrade of the Control Section is possible. The analysis for the existing highway section was performed in order to determine if deterioriation of the existing roadway could be partly attributed to frost action. Figure 13 indicates that frost could have penetrated to depths of almost three feet into the subgrade of the existing highway section, thus indicating that part of the deterioriation of the present roadway may be attributed to frost action.

Thicknesses of the existing pavement components vary from approximately $3\frac{1}{2}$ to 5 inches of bituminous material and approximately 5 to 9 inches of old road gravel. The thickness values used in the analysis were median values of the above, and therefore, the possibility exists that even deeper frost penetration occurred.

Width of Insulation

In Section "A" the insulation will be extended five feet beyond the edge of pavement, providing a total insulated width of 34 feet, while the insulation will be extended the full width of the shoulder in Section "B", providing a total insulated width of 46 feet.

The purpose of extending the insulation beyond the edge of pavement is to maximize the volume of subgrade subjected to one-dimensional heat flow. With reference to Figure 4, this means extending the insulation far enough beyond the edge of pavement to greatly reduce lateral heat transfer from the subgrade (the so-called "two-dimensional effect"). The optimal distance to extend the insulation to provide this protection is beyond analytical determination at this time. However, current research at

Purdue University is focused on the two-dimensional problem. Field data are needed to verify and refine the analysis. With instrumentation proposed in this report, interpretations of the heat flow patterns at the edges of the two different insulated widths can be made, which should prove valuable in the solution of the two-dimensional problem.

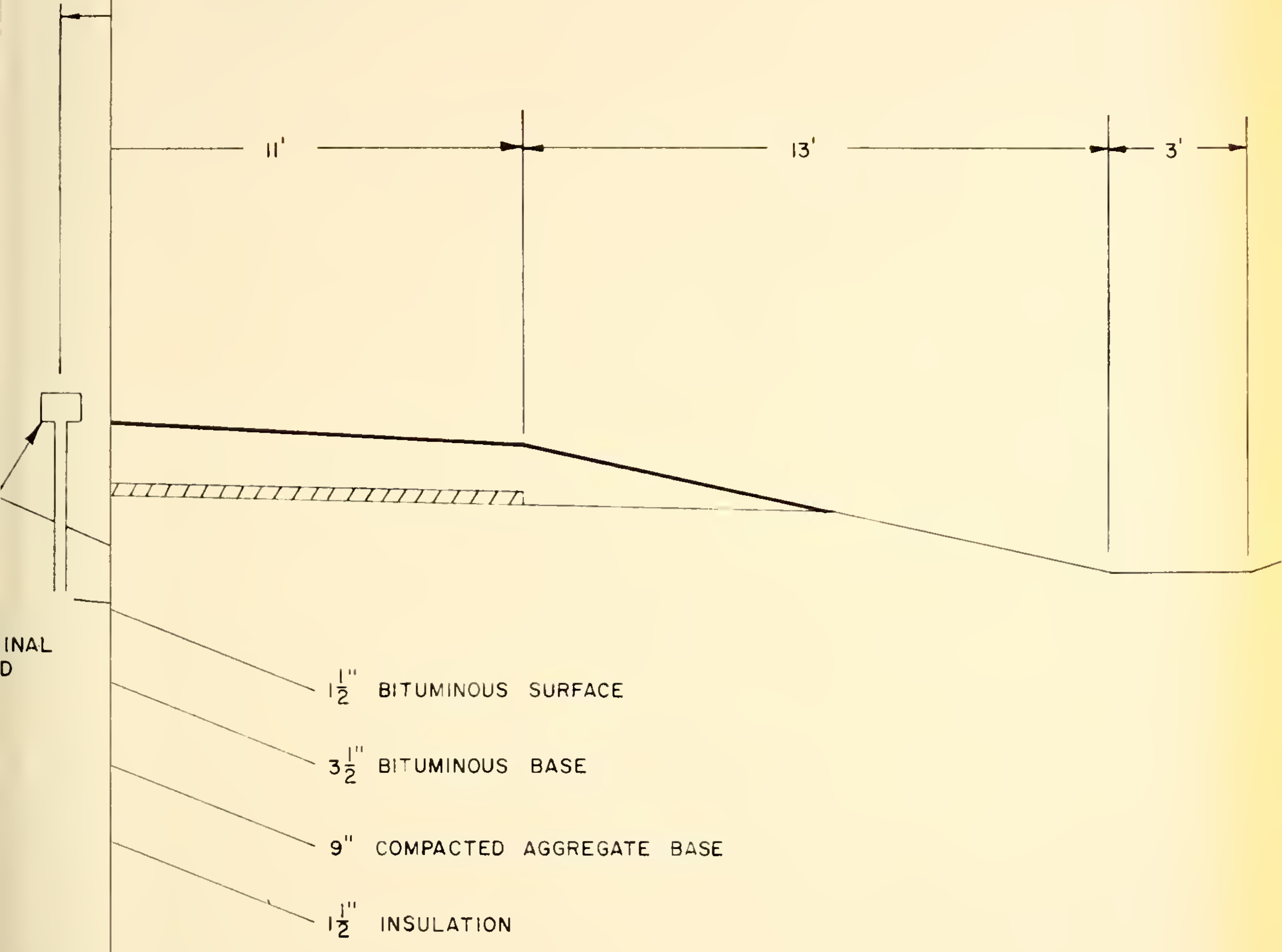
RECOMMENDED PERFORMANCE EVALUATION METHODS

Both the thermal and structural performance of the test sections will be investigated. If frost penetration through the insulation is substantially prevented, the structural performance of the insulated sections should prove superior to that of the non-insulated one. To evaluate the thermal and structural performance, the following methods are recommended.

Thermal Performance

To measure temperatures at various strategic locations throughout the cross-section of each of the three sections comprising the test installation, thermistors are recommended. Although thermocouples have been used in similar experimentation in other locations, thermistors are favored for reasons of durability, stability, ease of taking measurements, and economy. The thermistor units will be coated with epoxy and the leads will be encased in suitable plastic tubing for protection against the elements of the in-service environment.

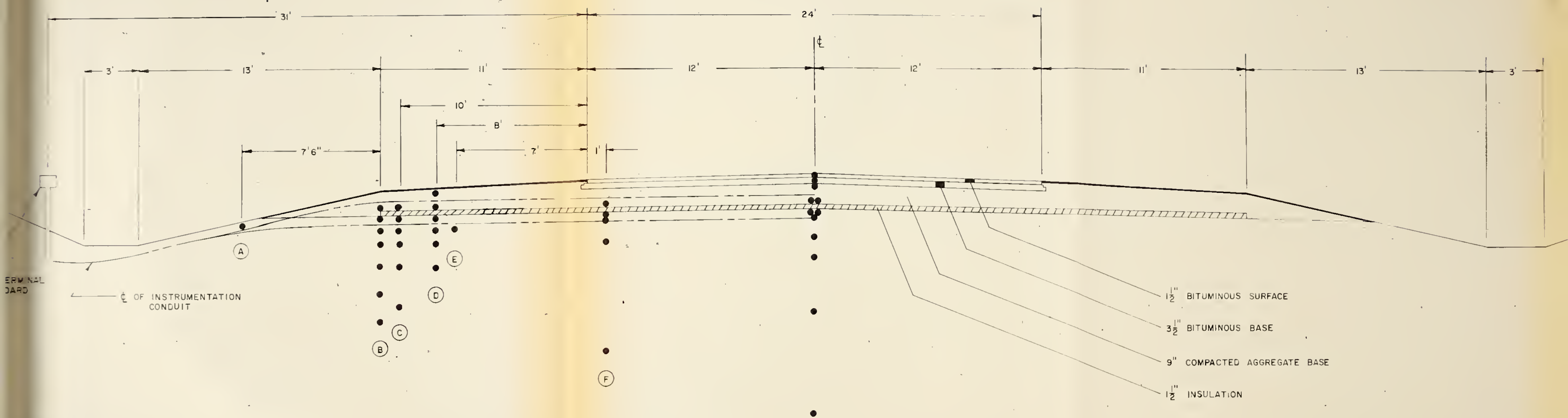
The recommended number and location of the thermistors for Sections "B", "C" and "A", are shown in Figures 14, 15 and 16, respectively. Section "B" contains 39 thermistors; Section "C", 24; and Section "A", 42... totaling 105 for the entire project. As shown in the Figures, the thermistors will be installed in vertical strings at the center section of each of the three sections. It is assumed that the thermal conditions will be symmetrical, and only one-half of any cross-section is instrumented. As explained in greater detail later in the report, all thermistors located in the subgrade will be installed in the side of a four foot trench, with the exception of



ERMISTOR

UMN
A
B
C
D
E
F
G

SCALE : HORIZ 1" = 4'
VERT 1" = 3'

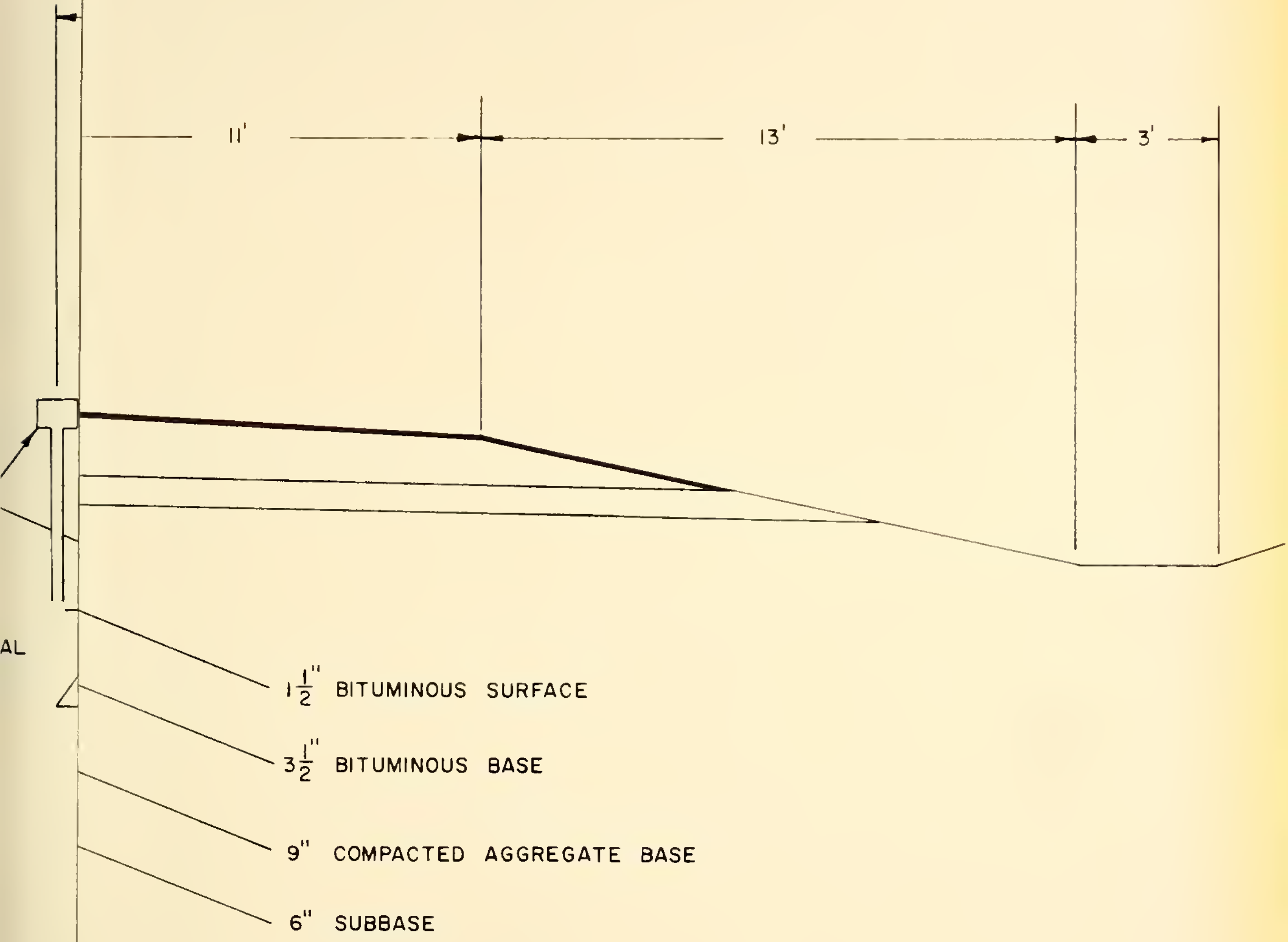


THERMISTORS — ●

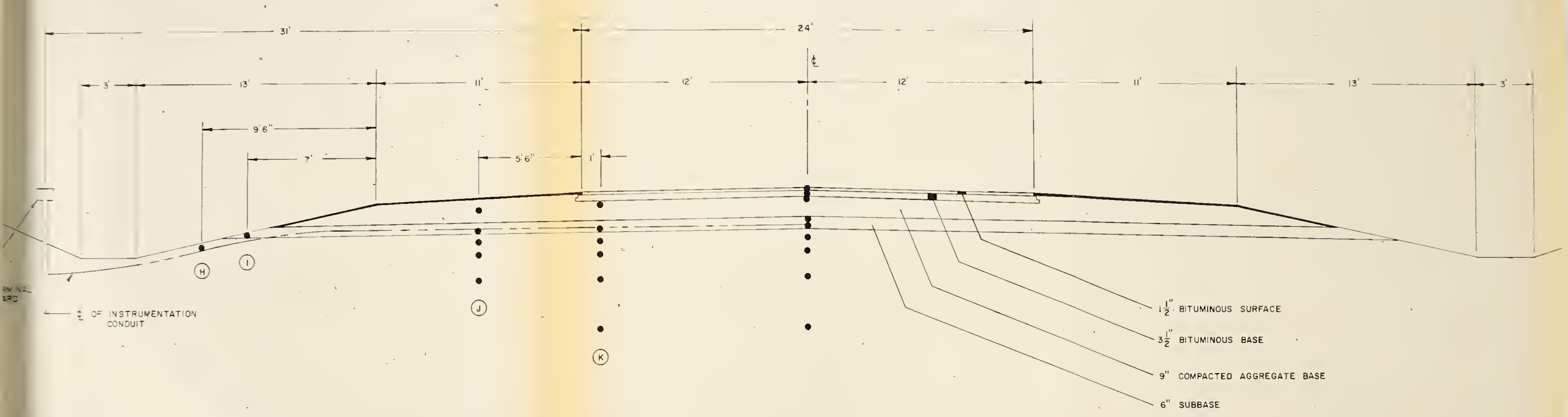
COLUMN	DISTANCE ABOVE TOP OF INSULATION (IN)	DISTANCE BELOW BOTTOM OF INSULATION (IN)
A		2" BELOW GROUND LINE
B	1	1, 7, $13\frac{1}{2}$, 24, 37, $49\frac{1}{2}$
C	1	1, 7, $13\frac{1}{2}$, 24, 43
D	, 8	1, 7, $13\frac{1}{2}$, 24
E		7
F		1, $3\frac{1}{2}$, $13\frac{1}{2}$, 65
G	1, , 8, $11\frac{1}{2}$, 13	1, 1, $3\frac{1}{2}$, $13\frac{1}{2}$, 24, $49\frac{1}{2}$, $97\frac{1}{2}$, $140\frac{1}{2}$

FIGURE 14. INSTRUMENTATION OF SECTION "B"
CROSS SECTION AT STA. 101+00

SCALE HORIZ 1" = 4'
VERT 1" = 3'



SCALE: HORIZ. 1" = 4'
VERT. 1" = 3'

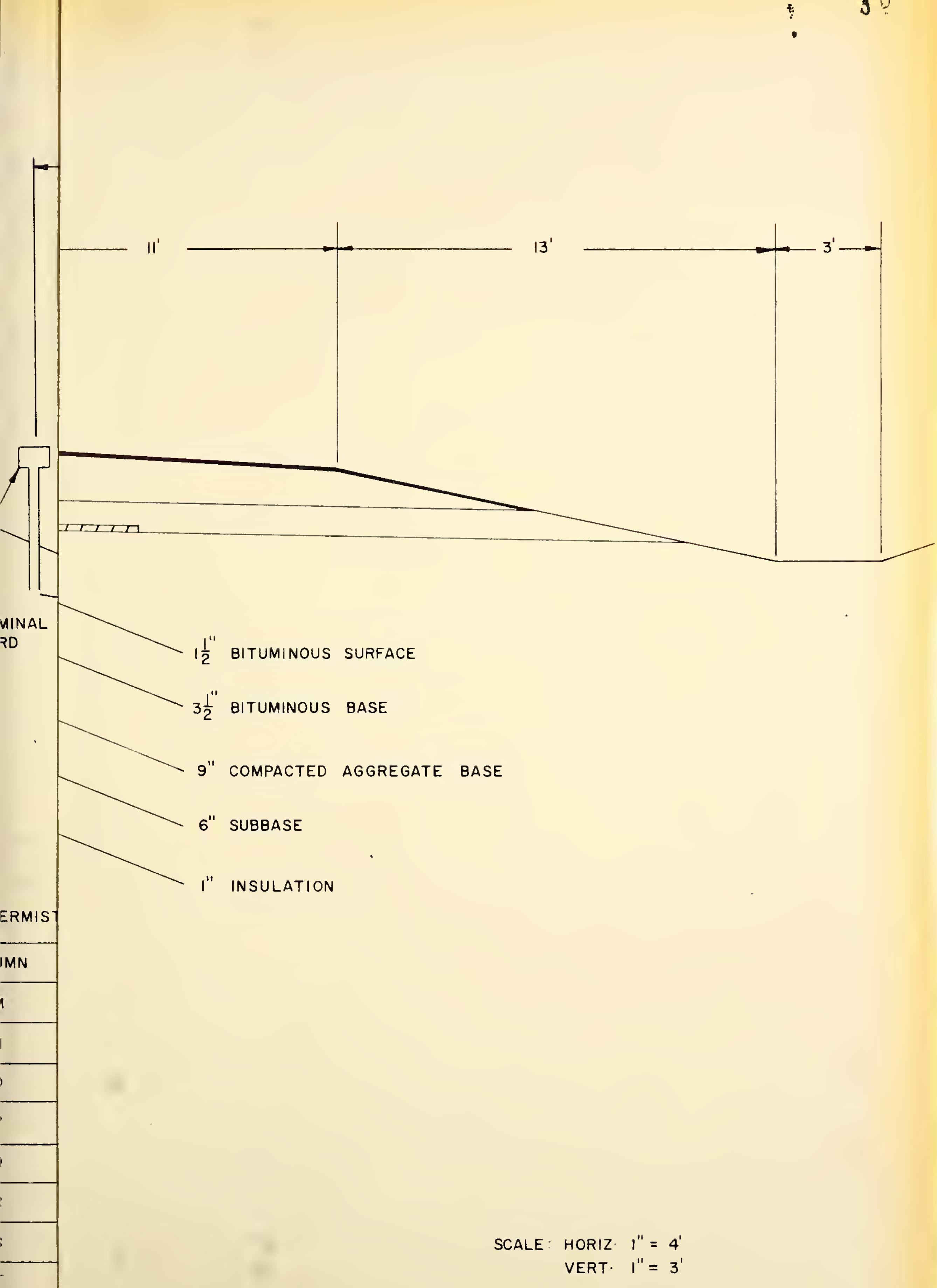


THERMISTORS — ●

COLUMN	DISTANCE ABOVE SUBGRADE (IN)	DISTANCE BELOW SUBGRADE (IN)
[illegible]		2" BELOW GROUND LINE
[illegible]		2" BELOW GROUND LINE
[illegible]	1, 14	3, 9, 21
[illegible]	1, 14	3, 9, 21, 45
[illegible]	, 5, 14, $17\frac{1}{2}$, 9	3, 9, 21, 45, 93, 136

FIGURE 15. INSTRUMENTATION OF SECTION "C"
CROSS SECTION AT STA. 103+00

SCALE: HORIZ 1" = 4'
VERT 1" = 3'


11'
13'
3'
MINAL
RD
1½" BITUMINOUS SURFACE
3½" BITUMINOUS BASE
9" COMPACTED AGGREGATE BASE
6" SUBBASE
1" INSULATION
ERMIST
MN
SCALE: HORIZ. 1" = 4'
VERT. 1" = 3'

THERMISTORS — ●

COLUMN	DISTANCE ABOVE TOP OF INSULATION (IN)	DISTANCE BELOW BOTTOM OF INSULATION (IN)
M		2" BELOW GROUND LINE
N		2" BELOW GROUND LINE
O	1, 14	1, 7, 13½, 24, 37, 49½
P		1, 7, 13½, 24, 43
Q		1, 7, 13½, 24
R		7
S	1	1, 3½
T		13½, 37, 66
U	1, 5, 14, 17½, 9	1, 1, 3½, 8, 24, 44, 92, 135

FIGURE 16. INSTRUMENTATION OF SECTION "A"
CROSS SECTION AT STA. 105 + 00

SCALE HORIZ 1" = 4'
VERT 1" = 3'

three thermistors in Section "B", two in Section "C", and three in Section "A". These eight elements are located at depths below the bottom of the trench, and will be installed in small diameter auger holes made through the bottom of the trench. At each section, all thermistor strings will be led out beneath the shoulder to a terminal board on the back slope.

The logic of the thermistor locations may be explained as follows. Thermistor columns A (Section "B"), H and I (Section "C"), and M and N (Section "A") were located to obtain information on the effect various surface materials have on the air-surface transfer factor. Thermistor columns B, C, D and E (Section "B") and columns O, P, Q, R and S (Section "A") were placed to measure the two-dimensional heat flow pattern at the edges of the insulation. As stated previously in the "Design Procedure" section, it is felt that valuable field data will be generated by these thermistors to help in the development of a two-dimensional heat flow prediction model. Such a model provides valuable guidance in the selection of width of the insulating layer.

Thermistor columns G (Section "B"), L (Section "C") and U(Section "A") were placed to measure the one-dimensional heat flow conditions at the center of the cross-sections and thus provide a check on the predictive capability of the extant one-dimensional model (9). The readings from these thermistors, with time, can be compared to prediction curves such as those of Figures 10, 11 and 12. The thermistors located immediately above and below the insulation in these columns are critical, and a pair is provided to allow for malfunctions. The two deepest thermistors in each of these center line columns are placed to obtain much needed information on the lower boundary conditions. Data from such depths are largely unavailable. The importance of properly assessing the lower boundary conditions in the design of an insulated pavement has

previously been stressed, with reference to Figure 7. The exact depths of the center-line thermistors, were selected with the idea of direct comparison of thermistor readings between sections, as shown in Figure 17.

In Section "C" thermistor columns J and K provide information on the heat flow conditions in the shoulder and at the edge of pavement, respectively. In addition, when these two columns are coupled with column L, a general picture of the thermal pattern for the cross-section is obtained.

Thermistor column T (Section "A") and F (Section "B") provide links between the temperature pattern at the edge of the insulation and the center line of their respective sections, and will allow construction of thermal contours. In addition, column F provides information on the heat flow at the edge of pavement.

Overall, it is felt that this instrumentation pattern can yield a superior description of the thermal regime of the three sections, and will provide highly useful input for checking both one and two-dimensional thermal prediction models.

Structural Performance

It is believed that for the purposes of this project, Benkelman beam tests offer the best means of comparing the structural performance of the insulated pavement sections with the control section. Other means of evaluating structural performance, such as the use of a roughometer or profilemeter, are concerned with determining a serviceability rating, which over the course of 15 to 20 years may only vary from four to two.

As reported by Turnbull, Ahlvin, and Brown (31), Benkelman deflection measurements graphically illustrate the occurrence of pavement failures during the period of thaw in areas of seasonal frost. Thus, Benkelman deflection measurements, besides giving an accurate determination of the deflection

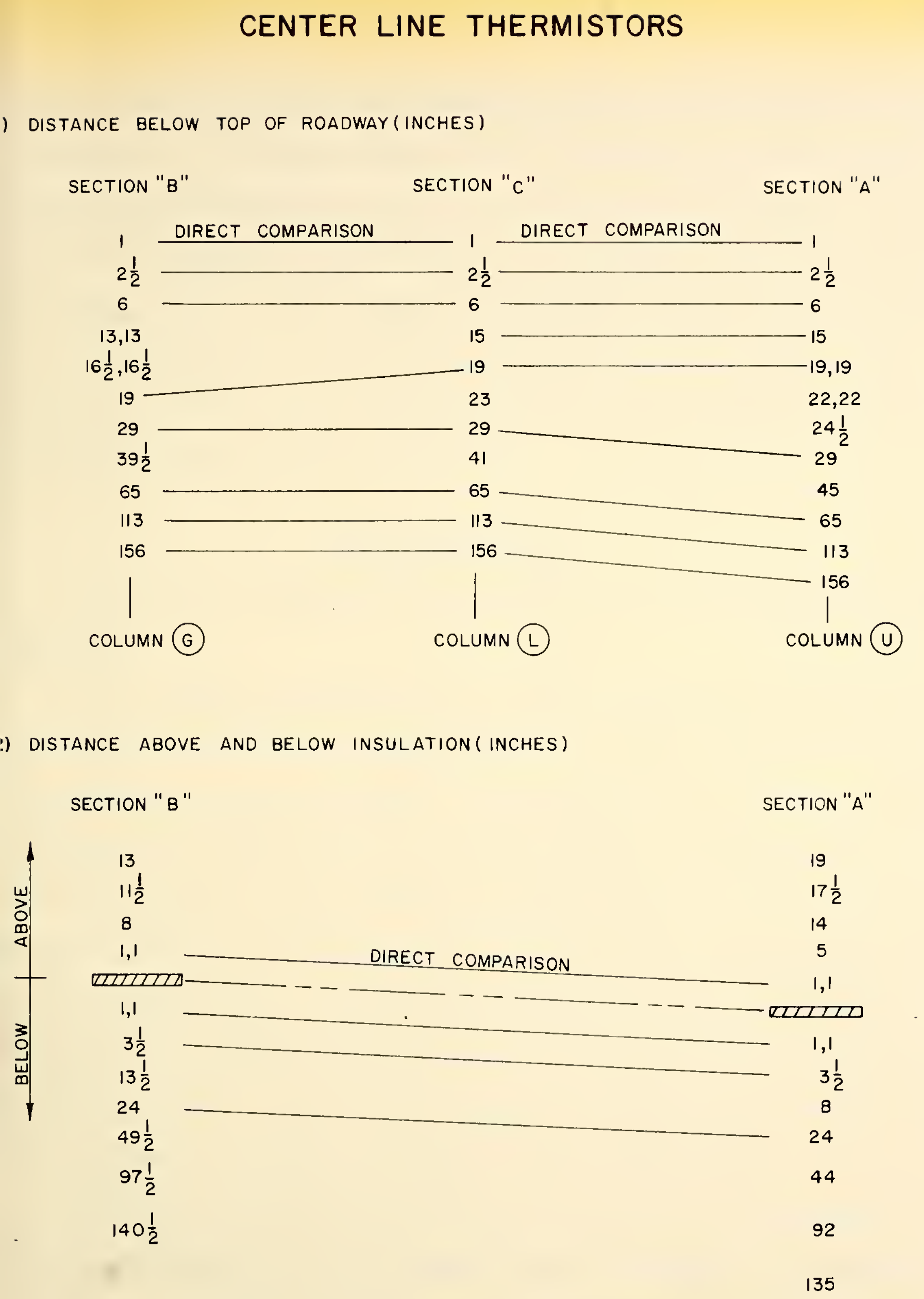


FIGURE 17. ILLUSTRATION OF DIRECT COMPARISONS AMONG CENTER LINE THERMISTORS

patterns of the test installation sections, will allow the effect of seasonal variations to be directly observed. It is recommended that these measurements be taken throughout the year...at the end of construction, during the fall, at the beginning of the winter, and, especially, several times during the spring warm-up. The thermal instrumentation will be particularly helpful in determining when Benkelman deflection measurements should be made. Comparative plots of these measurements with time will correlate structural performance with temperature and season.

Other Measurements

Several other measurements are recommended, with one being particularly important.

It is strongly recommended that a weather station be set up at about the center of the test installation (STA: 103 + 00) consisting of a standard rain gage and a 7-day thermograph. The thermograph will produce a continuous recording of air temperatures at the site, which can be interpreted in various ways to provide needed input for the upper boundary conditions of the thermal analysis. The thermograph should be protected in a standard U.S. Weather Bureau shelter. This shelter which protects the thermograph from precipitation, condensation and radiation, has louvered sides to permit air to circulate freely. The shelter should be installed with the bottom about four feet above the ground, and with the door facing north.

Monitoring of ground water levels at the site is also recommended. This can be accomplished in a simple perforated pipe kind of installation located at a convenient point on the lower backslope. This will provide information on one of the factors usually required to have frost action in a subgrade soil, namely a free supply of water.

RECOMMENDED CONSTRUCTION PROCEDURES

General

Construction procedures and specifications should follow those required y the Indiana State Highway Commission for flexible pavement roads, with xceptions to be noted in this report or deemed necessary by the Resident ngineer at the time of construction.

Due to the experimental nature of this project and the instrumentation o be installed, it will be necessary to place special restrictions on the ize and type of vehicles and equipment allowed on the test sections and ontrol section during construction. Sections "A" and "B" should be closed o all vehicles and equipment other than those required for the construction f the sections for a period from the final preparation of the subgrade hrough the completion of final paving. With the exception of the area adacent to the instrument locations, Section "C" can be open to such traffic s the Resident Engineer would normally permit. The area adjacent to the nstrument locations in Section "C" should be closed to all traffic except s required for construction. It will probably be necessary for the contractor to provide a temporary detour around the test installation.

After paving, the standard legal load restrictions will apply to each of the three sections. In addition, the use of lightweight equipment and special load restrictions may be imposed by the Project Supervisor or Resident Engineer for use in the construction of the test sections and instrumented area of the control section.

Construction Procedures

A. Test Sections With Insulating Layer

1. Subgrade Preparation

The compaction requirements for the soil on which the insulation is to be placed should be those normally specified by the engineer for

that soil. The surface on which the insulation board is to be placed may be leveled and smoothed by mechanical equipment as directed by the Engineer so that deviations from a 10 foot straight edge are not in excess of plus or minus ½ inch.

Thermistor Installation (Subgrade)

Hand labor and equipment for excavating, backfilling and recompacting a four foot deep trench (needed for installing the instrumentation) across one half of the roadway of each of the test sections, should be supplied by the contractor. The trench to be excavated in the subgrade should be backfilled with excavated subgrade material, and recompacted to meet the normal specification.

Installation of the instrumentation is not the responsibility of the contractor, but will be performed by staff from the Research and Training Center of the Indiana State Highway Commission, West Lafayette, or the Joint Highway Research Project. With reference to Figures 14, 15, and 16, it will be noted that in thermistor columns G, L and U, the two deepest thermistors are located at depths below the bottom of the excavated trench, while columns F and T also have their deepest thermistor below the bottom of the trench. These thermistors will be installed by lowering them to their specified locations through small diameter holes augered in the bottom of the trench. The subgrade material removed from the holes will be replaced and recompacted. These holes will be made by state forces, using state equipment (either hand or power auger).

A period of several days should be sufficient to excavate the trench, auger the holes, install the thermistors, backfill and recompact. Plastic coverings should be available to protect the trench, if rain occurs or threatens.

3. Placing Insulating Board

After the thermistors are placed in the subgrade, the contractor will provide the labor and equipment to install the insulating material upon the subgrade as directed by the Resident Engineer. The insulation will probably be supplied in sheets approximately 2' x 8' x 1" (Section "A") and 2' x 8' x $1\frac{1}{2}$" (Section "B"). The boards will be butted together and fixed in position with a minimum of two wooden skewers (approximately 6" by 3/8"ϕ) per sheet. The skewers should be driven through the insulation into the soil at an angle to force the board against the joint being formed,and until flush with the surface of the previously placed boards. Figure 18 illustrates this.

Placement of the insulating boards should begin at one end of the test section and proceed down the length of the section. The first row of boards is placed down the centerline of the roadway, using a stringline to insure straight alignment of the boards. Placement of the insulating boards should proceed from the center line outward, with the first row of boards always remaining ahead of the outer rows as placement advances. This is illustrated on Figure 19. In addition, all transverse joints should be staggered, as shown in Figure 20. To accomplish this, each adjacent row will be alternately displaced one-half the length of the boards (4 feet) for the full insulated width. Figure 21 illustrates this fingered pattern.

The area to be covered is 200' by ± 34' (6800 square feet) for Section "A", and 200' by ± 46' (9200 square feet) for Section "B". Previous experience indicates that the insulated board can be placed at about the rate of 800 bd. ft. per man per hour (36).

FIG. 18 PLACING STYROFOAM® HI-OTSEGO COUNTY, MICHIGAN (FROM 6)

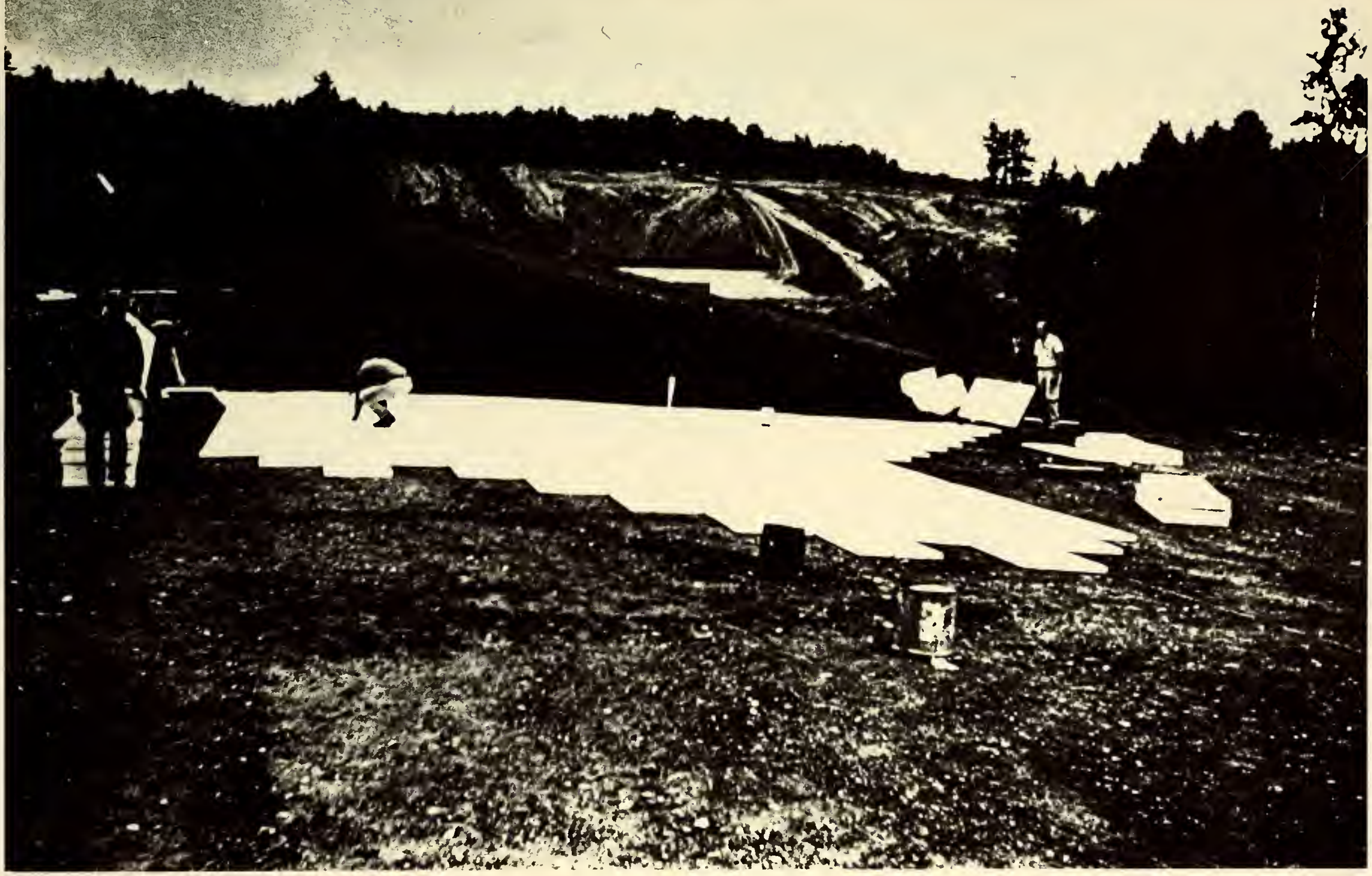


FIG. 19 PLACING STYROFOAM® HI - BANGOR, MAINE (FROM 6)

FIG. 20 PLACING STYROFOAM® HI - SAGINAW, MICHIGAN (FROM 6)

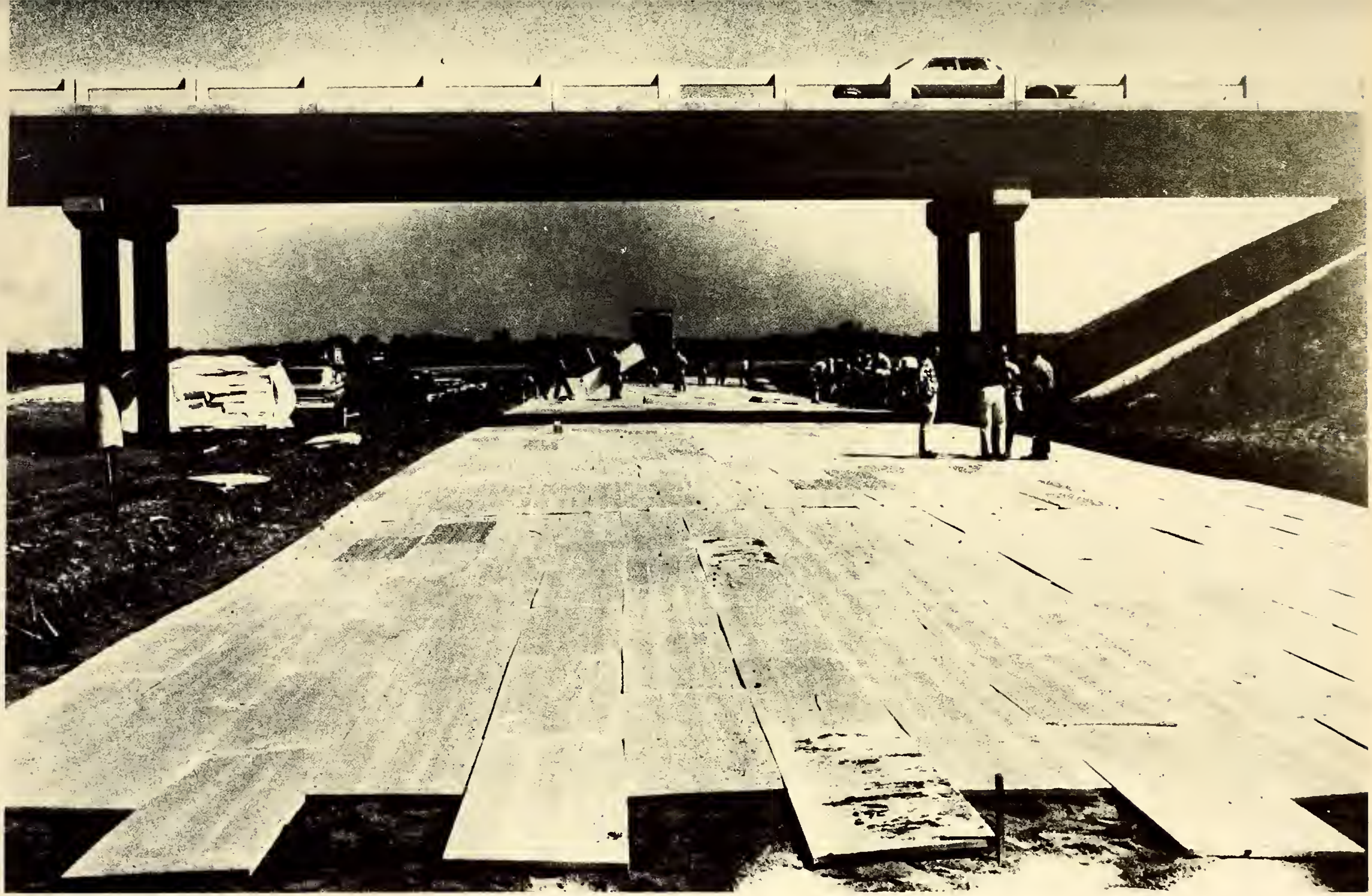


FIG. 21 INSULATED SECTION – OWATONNA, MINNESOTA (FROM 6)

4. Placement of Material on the Insulating Layer

As soon as the insulation is installed, the contractor should start construction of the overlying base or subbase. These courses will be constructed in the following manner:

Section "A"

The compacted thickness of Type II subbase will be not less than 6 inches. Accordingly, about an 8-inch loose lift should be placed and compacted. Coarse aggregate does not cause any appreciable damage to the surface of the insulation, as long as the top size of the material is less than approximately four inches and the material is well graded (36). Additional pertinent details of construction for this first lift are as follows. The material should first be end dumped adjacent to but not upon the insulation board, as shown in Figures 22 and 23. It should then be pushed onto the boards and spread by a lightweight track vehicle such as a front end loader. The vehicle should be equipped with street pads and operated in a manner such that at no time will it rest directly upon the insulation[1]; see Figures 24 and 25. Placement of material will be from one end only and proceed in the same direction the entire length of the section. Placing material from both ends simultaneously, may cause the boards in the center of the section to buckle up. Compaction of granular material on the insulation should be by equipment which exerts no more than an 80 psi contact pressure (37). Compaction of granular material on the insulation should be extended to the full width of the insulation before subsequent operations are performed, and should meet the normal specification requirements. There are no special restrictions on the

1. Extreme caution should be exercised by all equipment operators to avoid damage to the insulation and instruments.

FIG. 22 END DUMPING GRAVEL – MINNEAPOLIS, MINNESOTA (FROM 6)

FIG. 23 END DUMPING BASE – DUBOIS, WYOMING (FROM 6)

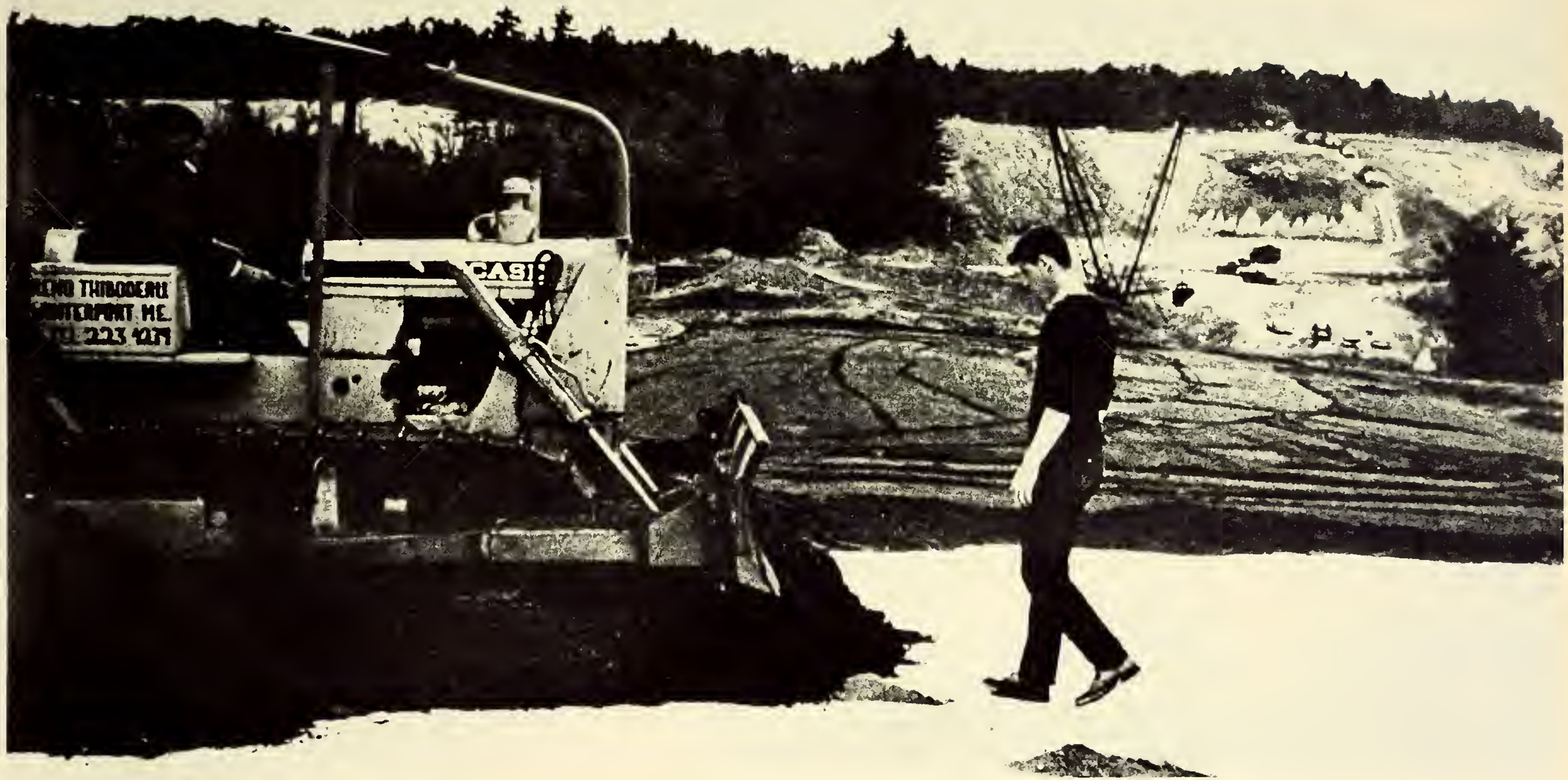


FIG. 24 SPREADING GRAVEL BASE – BANGOR, MAINE (FROM 6)

FIG. 25 SPREADING BASE – SUDBURY, ONTARIO (FROM 6)

FIG. 26 SPREADING BASE – SAGINAW, MICHIGAN (FROM 6)

placement of the 9-inch base which overlies the subbase. Conventional equipment required to complete the construction of the section may be allowed to operate on the base, once compacted.

Section "B"

A 6 inch thick compacted lift (or 8 inches thick loose) of Type "P" compacted aggregate base will be placed and compacted upon the insulation. A 3 inch thick (compacted) lift of the same material should then be placed and compacted. The construction methods for the first 6 inch compacted lift will be the same as those required for Section "A" in the preceding paragraph. The 3 inch compacted lift may be placed in a normal manner. Alternately the entire 9 inch base may be placed and compacted as a single lift, except that the special procedures described for Section "A" will apply...since this is the first lift above the insulation.

5. Thermistor Installation (Base Course To Wearing Course)

A trench will not be required to install thermistors above the insulating layer. As each such layer is completed, construction of the next layer will be deferred until state personnel have placed the instrumentation in the newly completed one. Placement of the instrumentation can be through small holes (large enough for a man's hand and lower arm) made at the thermistor locations in each layer. These holes will be refilled with material similar to that taken out.

6. Bituminous Base Course and Surface Course

The Resident Engineer will need to make certain value judgements in the use of heavy equipment to compact these layers. The principal item of concern will be damage to the thermistors and leads.

B. Control Section

The construction schedule for this section will be similar to the
sulated ones, except that the standard pavement section will be used.
e time relegated to the instrumentation of the various layers will
out the same as that for the insulated sections. Normal construction
thods and equipment will be used, except that the Engineer should be
ert to activities which could damage the thermal instrumentation.

FURTHER RECOMMENDATIONS

1. At the time of construction, or before, representative samples of generous proportions should be taken of: (a) each soil type used in the sections as compacted subgrade; (b) each soil type loaded in situ as pavement foundation, to the depth of the deepest thermistor; and (c) each granular material used as base or subbase.

2. Selected samples obtained in (1) above should be subjected to a program of laboratory evaluation for determining: (a) standard indices of classification, compaction, and load-deformation; and (b) such thermal characteristics as are deemed practicable and desirable.

3. A program of data collection, reduction and analysis should be established which will serve: (a) to correlate the pavement sections performance with their transient environment; and (b) to validate, refine, and extend analytical models for thermal pavement design.

4. A detailed program for implementing the recommendations of (1,2,3) above should be developed jointly by the Research and Training Center and the Joint Highway Research Project, and be submitted to the appropriate State authority for review and action. Since construction of the test facility is imminent, there is some urgency to this recommendation.

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APPENDIX A

PREDICTION OF TEMPERATURE WITH TIME AND DEPTH

FIGURE 27. PREDICTION OF TEMPERATURE DISTRIBUTION
ONE-DIMENSIONAL HEAT FLOW

No. ____________ Date March 8, 1968 By Stulgis

CASE Test Section "A" (1" Insulation), State Road 26 - Rossville

ASSUMPTIONS

Initial Condition Constant (50°F)

Boundary Condition M.D.T. as step input (Nov. 1, 1962 - March 31, 1963)

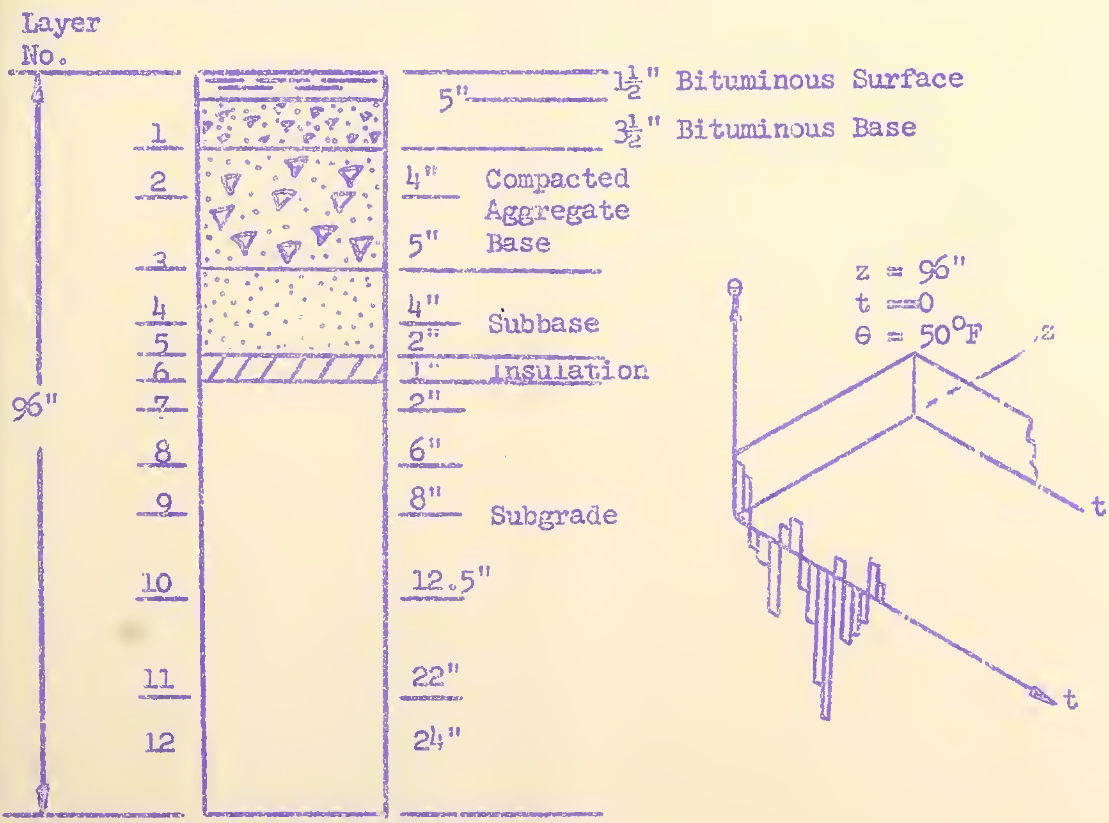
Lower Boundary Condition Constant (50°F) at depth of 96"

Air-Surface Correction Factor 0.99

COMPUTER

Type IBM-7094 Language FORTRAN IV Execute Time 192.6 sec.

SKETCH OF PROFILE AND BOUNDARIES



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~~59~~

FCR PREDICTING OF FROST PENETR

HIGHWAY RESEARCH PROJECT PUR
OAK HI TEST INSTALLATION
ROAD 26 ROSSVILLE
ECTION NO. "A" 1.0 INCH OF F
DATA 1962/1963 R. STULCIS

L NUMBER OF LAYERS DIVIDED

LAYE	THICKNESS FEET	DRY UNIT PCF
1	0.4167	143.(
2	0.3333	145.(
3	0.4167	145.(
4	0.3333	120.(
5	0.1667	120.(
6	0.0833	1.[illegible]
7	0.1667	108.(
8	0.5000	108.(
9	0.6667	108.(
10	1.0417	108.(
11	1.8333	108.(
12	2.0000	108.(

LAYE	VOLUMETRIC HEA BTU/C.F. F
1	C= 0. T + 3
2	C= 0. T + 2
3	C= 0. T + 2
4	C= 0. T + 2
5	C= 0. T + 2
6	C= 0. T + (
7	C= 0. T + 2
8	C= 0. T + 2
9	C= 0. T + 2
10	C= 0. T + 2
11	C= 0. T + 2
12	C= 0. T + 2

LAYER	ICE FORMATION C T(
1	NO ICE WILL BE FO
2	PERCENT WC FROZEN
3	PERCENT WC FROZEN
4	PERCENT WC FROZEN
5	PERCENT WC FROZEN
6	NO ICE WILL BE FC
7	PERCENT WC FROZEN
8	PERCENT WC FROZEN

TA FOR PREDICTING OF FROST PENETRATION INTO A SOIL-WATER SYSTEM

NT HIGHWAY RESEARCH PROJECT PURDUE UNIVERSITY
RCFOAM HI TEST INSTALLATION
TE ROAD 26 ROSSVILLE
T SECTION NO. "A" 1.0 INCH OF FOAM
P. DATA 1962/1963 R. STULCIS

OTAL NUMBER OF LAYERS DIVIDED 12

LAYE	THICKNESS FEET	DRY UNIT WT PCF	WATER CONTENT PERCENT	DEPTH(BELOW SURFACE) FEET
1	0.4167	143.0	0.	0. - 0.4167
2	0.3333	145.0	4.00	0.4167 - 0.7500
3	0.4167	145.0	4.00	0.7500 - 1.1667
4	0.3333	120.0	4.80	1.1667 - 1.5000
5	0.1667	120.0	4.80	1.5000 - 1.6667
6	0.0833	1.8	0.	1.6667 - 1.7500
7	0.1667	108.0	17.00	1.7500 - 1.9167
8	0.5000	108.0	17.00	1.9167 - 2.4167
9	0.6667	108.0	17.00	2.4167 3.0834
10	1.0417	108.0	17.00	3.0834 - 4.1251
11	1.8333	108.0	17.00	4.1251 - 5.9584
12	2.0000	108.0	17.00	5.9584 - 7.9584

LAYE	VOLUMETRIC HEAT BTU/C.F. F	CONDUCTIVITY BTU/FT-HR-F
1	C= 0. T + 30.500	K= 0. T + 0.840
2	C= 0. T + 25.400	K= 0. T + 1.900
3	C= 0. T + 25.400	K= 0. T + 1.900
4	C= 0. T + 25.400	K= 0. T + 1.900
5	C= 0. T + 25.400	K= 0. T + 1.900
6	C= 0. T + 0.500	K= 0. T + 0.022
7	C= 0. T + 21.000	K= 0. T + 1.170
8	C= 0. T + 21.000	K= 0. T + 1.170
9	C= 0. T + 21.000	K= 0. T + 1.170
10	C= 0. T + 21.000	K= 0. T + 1.170
11	C= 0. T + 21.000	K= 0. T + 1.170
12	C= 0. T + 21.000	K= 0. T + 1.170

LAYE	ICE FORMATION CURVE IN EXPONANTIAL FUNCTION T(J,K) IN CENTIGRADE
1	NO ICE WILL BE FORMED IN THIS LAYER, SINCE NO WATER IS PRESENT
2	PERCENT WC FROZEN =100.00 - EXP(0.300 *T(J,K) + 4.600)
3	PERCENT WC FROZEN =100.00 - EXP(0.300 *T(J,K) + 4.600)
4	PERCENT WC FROZEN =100.00 - EXP(0.300 *T(J,K) + 4.600)
5	PERCENT WC FROZEN =100.00 - EXP(0.300 *T(J,K) + 4.600)
6	NO ICE WILL BE FORMED IN THIS LAYER, SINCE NO WATER IS PRESENT
7	PERCENT WC FROZEN = 62.00 - EXP(0.457 *T(J,K) + 4.132)
8	PERCENT WC FROZEN = 62.00 - EXP(0.457 *T(J,K) + 4.132)

9 PERCENT WC FROZEN
10 PERCENT WC FROZEN
11 PERCENT WC FROZEN
12 PERCENT WC FROZEN

NITIAL CONDITION INITIA

NCREMENT OF TIME, DT = 0.500 H
OTAL DURATION OF TIME = 3612.0 H

UNDARY CONDITIONS IN FORM OF STE

NO OF STEP	TIME INTERV
1	0. -
2	24.000 -
3	48.000 -
4	72.000 -
5	96.000 -
6	120.000 -
7	144.000 -
8	168.000 -
9	192.000 -
10	216.000 -
11	240.000 -
12	264.000 -
13	288.000 -
14	312.000 -
15	336.000 -
16	360.000 -
17	384.000 -
18	408.000
19	432.000 -
20	456.000 -
21	480.000 -
22	504.000 -
23	528.000 -
24	552.000
25	576.000 -
26	600.000 -
27	624.000 -
28	648.000 -
29	672.000 -
30	696.000 -
31	720.000 -
32	744.000 -
33	768.000 -
34	792.000 -
35	816.000 -
36	840.000 -
37	864.000 -
38	888.000 -
39	912.000 -
40	936.000 -

```
 9     PERCENT WC FROZEN = 62.00 - EXP( C.457 *T(J,K) +  4.132 )
10     PERCENT WC FROZEN = 62.00 - EXP( C.457 *T(J,K) +  4.132 )
11     PERCENT WC FROZEN = 62.00 - EXP( C.457 *T(J,K) +  4.132 )
12     PERCENT WC FROZEN = 62.00 - EXP( C.457 *T(J,K) +  4.132 )
```

INITIAL CONDITION   INITIAL TEMPERATURE = CONSTANT FOR ALL DEPTH =   50.0000 DEGREE FAHR

INCREMENT OF TIME, DT = 0.500 HOURS
TOTAL DURATION OF TIME = 3612.0 HOURS = 150 DAYS AND 12 HOURS

BOUNDARY CONDITIONS IN FORM OF STEP FUNCTION

NO OF STEP	TIME INTERVAL(HOURS)			TEMPERATURE
1	0.	-	24.000	40.000
2	24.000	-	48.000	41.000
3	48.000	-	72.000	40.000
4	72.000	-	96.000	41.000
5	96.000	-	120.000	35.000
6	120.000	-	144.000	38.000
7	144.000	-	168.000	39.000
8	168.000		192.000	44.000
9	192.000	-	216.000	37.000
10	216.000	-	240.000	40.000
11	240.000		264.000	38.000
12	264.000	-	288.000	38.000
13	288.000	-	312.000	39.000
14	312.000	-	336.000	42.000
15	336.000	-	360.000	44.000
16	360.000	-	384.000	50.000
17	384.000	-	408.000	44.000
18	408.000		432.000	35.000
19	432.000	-	456.000	36.000
20	456.000	-	480.000	35.000
21	480.000	-	504.000	41.000
22	504.000	-	528.000	41.000
23	528.000	-	552.000	31.000
24	552.000		576.000	38.000
25	576.000	-	600.000	35.000
26	600.000	-	624.000	36.000
27	624.000	-	648.000	38.000
28	648.000	-	672.000	39.000
29	672.000	-	696.000	41.000
30	696.000	-	720.000	46.000
31	720.000	-	744.000	46.000
32	744.000	-	768.000	44.000
33	768.000	-	792.000	44.000
34	792.000	-	816.000	42.000
35	816.000	-	840.000	44.000
36	840.000	-	864.000	29.000
37	864.000	-	888.000	23.000
38	888.000	-	912.000	25.000
39	912.000	-	936.000	26.000
40	936.000	-	960.000	15.000

57

~~55~~

41	960.000	-	984.000	10.000
42	984.000	-	1008.000	0.
43	1008.000	-	1032.000	2.000
44	1032.000	-	1056.000	11.000
45	1056.000	-	1080.000	17.000
46	1080.000	-	1104.000	31.000
47	1104.000	-	1128.000	30.000
48	1128.000	-	1152.000	37.000
49	1152.000	-	1176.000	43.000
50	1176.000	-	1200.000	40.000
51	1200.000	-	1224.000	29.000
52	1224.000	-	1248.000	21.000
53	1248.000	-	1272.000	24.000
54	1272.000	-	1296.000	11.000
55	1296.000	-	1320.000	14.000
56	1320.000	-	1344.000	14.000
57	1344.000	-	1368.000	5.000
58	1368.000	-	1392.000	16.000
59	1392.000	-	1416.000	20.000
60	1416.000	-	1440.000	20.000
61	1440.000	-	1464.000	14.000
62	1464.000	-	1488.000	14.000
63	1488.000	-	1512.000	22.000
64	1512.000	-	1536.000	28.000
65	1536.000	-	1560.000	31.000
66	1560.000	-	1584.000	29.000
67	1584.000	-	1608.000	32.000
68	1608.000	-	1632.000	27.000
69	1632.000	-	1656.000	28.000
70	1656.000	-	1680.000	35.000
71	1680.000	-	1704.000	43.000
72	1704.000	-	1728.000	36.000
73	1728.000	-	1752.000	29.000
74	1752.000	-	1776.000	13.000
75	1776.000	-	1800.000	6.000
76	1800.000	-	1824.000	6.000
77	1824.000	-	1848.000	-2.000
78	1848.000	-	1872.000	12.000
79	1872.000	-	1896.000	20.000
80	1896.000	-	1920.000	27.000
81	1920.000	-	1944.000	9.000
82	1944.000	-	1968.000	-2.000
83	1968.000	-	1992.000	7.000
84	1992.000	-	2016.000	8.000
85	2016.000	-	2040.000	-12.000
86	2040.000	-	2064.000	0.
87	2064.000	-	2088.000	6.000
88	2088.000	-	2112.000	6.000
89	2112.000	-	2136.000	-6.000
90	2136.000	-	2160.000	-3.000
91	2160.000	-	2184.000	13.000
92	2184.000	-	2208.000	5.000
93	2208.000	-	2232.000	5.000
94	2232.000	-	2256.000	28.000
95	2256.000	-	2280.000	14.000
96	2280.000	-	2304.000	10.000
97	2304.000	-	2328.000	30.000
98	2328.000	-	2352.000	33.000
99	2352.000	-	2376.000	40.000
100	2376.000	-	2400.000	23.000
101	2400.000	-	2424.000	15.000

58 ~~56~~

102	2424.000 -	2448.000	22.000
103	2448.000 -	2472.000	25.000
104	2472.000 -	2496.000	13.000
105	2496.000 -	2520.000	12.000
106	2520.000 -	2544.000	14.000
107	2544.000 -	2568.000	4.000
108	2568.000 -	2592.000	6.000
109	2592.000 -	2616.000	17.000
110	2616.000 -	2640.000	33.000
111	2640.000 -	2664.000	39.000
112	2664.000 -	2688.000	39.000
113	2688.000 -	2712.000	15.000
114	2712.000 -	2736.000	-2.000
115	2736.000 -	2760.000	6.000
116	2760.000 -	2784.000	18.000
117	2784.000 -	2808.000	16.000
118	2808.000 -	2832.000	1.000
119	2832.000 -	2856.000	-4.000
120	2856.000 -	2880.000	15.000
121	2880.000 -	2904.000	25.000
122	2904.000 -	2928.000	13.000
123	2928.000 -	2952.000	22.000
124	2952.000 -	2976.000	41.000
125	2976.000 -	3000.000	38.000
126	3000.000 -	3024.000	32.000
127	3024.000 -	3048.000	35.000
128	3048.000 -	3072.000	35.000
129	3072.000 -	3096.000	39.000
130	3096.000 -	3120.000	35.000
131	3120.000 -	3144.000	35.000
132	3144.000 -	3168.000	39.000
133	3168.000 -	3192.000	43.000
134	3192.000 -	3216.000	32.000
135	3216.000 -	3240.000	31.000
136	3240.000 -	3264.000	37.000
137	3264.000 -	3288.000	50.000
138	3288.000 -	3312.000	38.000
139	3312.000 -	3336.000	42.000
140	3336.000 -	3360.000	47.000
141	3360.000 -	3384.000	34.000
142	3384.000 -	3408.000	30.000
143	3408.000 -	3432.000	36.000
144	3432.000 -	3456.000	52.000
145	3456.000 -	3480.000	61.000
146	3480.000 -	3504.000	55.000
147	3504.000 -	3528.000	38.000
148	3528.000 -	3552.000	52.000
149	3552.000 -	3576.000	61.000
150	3576.000 -	3600.000	65.000
151	3600.000 -	3624.000	65.000

RRECTION FACTOR FOR BOUNDARY VALUES FOR AIR GROUND INTERFACE = 0.990

MP AT LOWER BDY EQUALS TO THE TEMP SPECIFIED(50.00 FAHR)

```
ECUTE        IBJOB
JOB
FTC MAIN

*********************************************************************
**     THIS PROGRAM IS PREPARED FOR THE PREDICTION OF TEMPERATURE  **
**  DISTRIBUTION IN AN ARBITRARY MEDIA UNDER VARIOUS INITIAL AND   **
**  BOUNDARY CONDITIONS  --ONE DIMENSIONAL ANALYSIS--              **
*********************************************************************

  DIMENSION T(16,500),ID(90)
  DIMENSION Z(15),DEN(15),WC(15),ZZ(15),SPHT(15),COND(15)
  DIMENSION C1(15),C2(15),C3(15),C4(15),C5(15),C6(15),C7(15)
  DIMENSION STEPA(15),STEPB(15),STEPT(15),TF(15),ICE(15)
  DIMENSION STEBA(999),STEBB(999),STEBT(999),TB(999),TBL(999)
  COMMON C1,C2,C3,C4,C5,C6,C7,T,SPHT,COND,DEN,WC,J,K,M,Z,D
 1     ,TB,TBL,DTFOAM,JFOAM,LBOND
  DATA CGS,FPH,CENT,FAHR/3HCGS,3HFPH,4HCENT,4HFAHR/,TFREZ/0./
 1  ,CELL/500./

*********************************************************************
** SOIL PROFILE AND ITS PROPERTIES    ******************************
**   ONE DIMENSIONAL ANALYSIS         ******************************
*********************************************************************

---------------------------------------------------------------------
I  SUBSCRIPTS J, K DENOTING SPACE AND TIME STEPS RESPECTIVELY       I
I    J,K=1,2,3,...                                                  I
---------------------------------------------------------------------


00 READ(5,9) ID
  READ(5,10) UNITS,TICE,TEMPI,TEMPB,TEMPO
  READ(5,11) M
  READ(5,12) (Z(J),DEN(J),WC(J), J=1,M)

  CHECK STOP FOR NEGATIVE OR ZERO THICKNESS AND DRY UNIT WEIGHT AND
    NEGATIVE WATER CONTENT
  DO 70 J=1,M
  IF(Z(J).LE.0.0) GO TO 71
  IF(DEN(J).LE.0.0) GO TO 72
  IF(WC(J).LT.0.0) GO TO 73
70 CONTINUE
  GO TO 74
71 WRITE(6,75)
75 FORMAT(1H1,39HNEGATIVE OR ZERO THICKNESS, CHECK INPUT)
  STOP
72 WRITE(6,76)
76 FORMAT(1H1,45HNEGATIVE OR ZERO DRY UNIT WEIGHT, CHECK INPUT)
  STOP
```

```
73 WRITE(6,77)
77 FORMAT(1H1,35HNEGATIVE WATER CONTENT, CHECK INPUT)
   STOP

74 WRITE(6,101)
101 FORMAT(1H1,65HDATA FOR PREDICTING OF FROST PENETRATION INTO A SOIL
  1-WATER SYSTEM///)
   WRITE(6,9) ID
   WRITE(6,102) M
102 FORMAT(//2X30HTOTAL NUMBER OF LAYERS DIVIDED, I5///,7X5HLAYER,3X
  1  9HTHICKNESS,3X11HDRY UNIT WT,5X13HWATER CONTENT,10X
  2 20HDEPTH(BELOW SURFACE))
   IF(UNITS.EQ.CGS) WRITE(6,103)
   IF(UNITS.EQ.FPH) WRITE(6,109)
103 FORMAT(19X1HM,9X7HKG/C.M.,10X7HPERCENT,22X1HM)
109 FORMAT(18X4HFEET,9X3HPCF,12X7HPERCENT,21X4HFEET)

   ZZ(1)=0.0
   DO 90 J=1,M
90 ZZ(J+1)=ZZ(J)+Z(J)

   WRITE(6,104) (J,Z(J),DEN(J),WC(J),ZZ(J),ZZ(J+1), J=1,M)
104 FORMAT(I10,F13.4,5X,F8.1,8X,F8.2,15XF7.4,3H = ,F7.4)

   IF(UNITS.EQ.CGS) GO TO 100
   DO 99 J=1,M
   Z(J)=Z(J)*0.3048
99 DEN(J)=DEN(J)*16.01837


C------------------------------------------------------------------------
C I  READ VOLUMETRIC HEAT AND THERMAL CONDUCTIVITY OF ALL LAYERS,      I
C I    WHICH ARE ASSUMED, VARIES LINEARLY WITH TEMPERATURE, I.E.       I
C I      VOLUMETRIC HEAT = C1*(TEMP) + C2                              I
C I      CONDUCTIVITY = C3*(TEMP) + C4                                 I
C I    WHERE C1, C2, C3, AND C4 ARE CONSTANTS                          I
C------------------------------------------------------------------------

100 READ(5,13) (C1(J),C2(J),C3(J),C4(J), J=1,M)
   WRITE(6,105)
105 FORMAT(/////7X5HLAYER,9X15HVOLUMETRIC HEAT,10X12HCONDUCTIVITY/)
   IF(UNITS.EQ.CGS) WRITE(6,115)
   IF(UNITS.EQ.FPH) WRITE(6,116)
115 FORMAT(23X11HKCAL/C.M.-C,13X11HKCAL/M-HR-C)
116 FORMAT(23X10HBTU/C.F.-F,13X11HBTU/FT-HR-F)

   DO 110 J=1,M
110 WRITE(6,114) J,C1(J),C2(J),C3(J),C4(J)
114 FORMAT(I10,10X2HC=,F7.2,4H T +,F7.3,4X2HK=,F7.2,4H T +,F7.3)

   IF(UNITS.NE.FPH) GO TO 107
   DO 98 J=1,M
   C2(J)=(C2(J)+C1(J)*32.0)*16.05
   C1(J)=C1(J)*16.05
   C4(J)=(C4(J)+C3(J)*32.0)*1.488
98 C3(J)=C3(J)*1.488


C************************************************************************
C** ICE FORMATION CHARACTERISTICS                                    ***
C**   ASSUME THAT FOR EACH LAYER, THE PERCENT MOISTURE FROZEN IS     ***
```

```
**    AN EXPONANTIAL FUNCTION OF TEMPERATURE,
**      PERCENT MOISTURE FROZEN = C5 - EXP( C6 * TEMP - C7 )                    ***
**    WHERE C5, C6, AND C7 ARE CONSTANTS                                        ***
**    READ 1 FOR KNOWN COEFFICIENTS                                             ***
**         2 FOR DATA TO BE FITTING INTO AN EXPONANTIAL FUNCTION                ***
**         3 FOR DRY LAYER                                                      ***
****************************************************************************************

107 DO 108 J=1,M

    READ(5,11) ICE(J)
    ICEJ=ICE(J)
    GO TO (121,122,123), ICEJ

122 IF(TICE.EQ.CENT) ICORF=1
    IF(TICE.EQ.FAHR) ICORF=2

    CALL CURVE(C55,C66,C77,ICORF)
    C5(J)=C55
    C6(J)=C66
    C7(J)=C77
    GO TO 108

121 READ(5,12) C5(J),C6(J),C7(J)
    GO TO 108

123 C5(J)=1.0
    C6(J)=0.0
    C7(J)=0.0
    GO TO 108

108 CONTINUE

    WRITE(6,117)
117 FORMAT(/////7X5HLAYER,8X43HICE FORMATION CURVE IN EXPONANTIAL FUNC
   1TION)
    IF(TICE.EQ.CENT) WRITE(6,125)
    IF(TICE.EQ.FAHR) WRITE(6,126)
125 FORMAT(33X20HT(J,K) IN CENTIGRADE)
126 FORMAT(33X20HT(J,K) IN FAHRENHEIT)
    DO 106 J=1,M
    IF(ICE(J).EQ.3) GO TO 124
    WRITE(6,118) J,C5(J),C6(J),C7(J)
118 FORMAT(I10,8X19HPERCENT WC FROZEN =,F6.2,7H - EXP(,F6.3,11H *T(J,K
   1) + ,F6.3,2H ))
    GO TO 106

124 WRITE(6,119) J
119 FORMAT(I10,8X62HNO ICE WILL BE FORMED IN THIS LAYER, SINCE NO WATE
   1R IS PRESENT)
    GO TO 106
106 CONTINUE

    IF(TICE.EQ.CENT) GO TO 200
    DO 95 J=1,M
    C7(J)=C7(J)+C6(J)*32.0
95  C6(J)=C6(J)*9.0/5.0


****************************************************************************************
** INITIAL CONDITION ,T(J,1)     J=1,2,...,M                                         **
```

```
**    READ 1 FOR CONSTANT                                                       **
**         2 FOR ALGEBRAIC FUNCTION                                             **
**         3 FOR TRIGONOMETRIC FUNCTION                                         **
**         4 FOR STEP FUNCTION                                                  **
**         5 FOR DATA TO BE FITTING INTO AN ALGBRAIC FUNCTION                   **
**         6 FOR KNOWN TEMP. AT MID-POINT OF ALL LAYERS                         **
**********************************************************************************

200 READ(5,11) INIT
    GO TO (201,202,203,204,205,206), INIT

----------------------------------------------------------------------------------
I   T(Z,1)=CONSTANT FOR ALL Z                                                    I
----------------------------------------------------------------------------------

201 READ(5,12) TINIT
    TIB=TINIT
    DO 221 J=1,M
221 T(J,1)=TINIT
    TBL(1)=TINIT
    WRITE(6,23) TINIT,TEMPI
 23 FORMAT(///2X17HINITIAL CONDITION,10X,46HINITIAL TEMPERATURE = CONS
   1TANT FOR ALL DEPTH =,F10.4,8H DEGREE ,A4)
    GO TO 299

----------------------------------------------------------------------------------
I   T(Z,1)=A+B*Z+C*Z**2+D*Z**3                                                   I
----------------------------------------------------------------------------------

202 READ(5,13) AINI,BINI,CINI,DINI
    TIB=AINI
    DDZ=Z(1)/2.0
    DO 225 J=1,M
    T(J,1)=AINI+BINI*DDZ+CINI*DDZ**2+DINI*DDZ**3
225 DDZ=DDZ+Z(J)/2.0+Z(J+1)/2.0
    TBL(1)=AINI+BINI*DDZ+CINI*DDZ**2+DINI*DDZ**3
    WRITE(6,24) AINI,BINI,CINI,DINI
 24 FORMAT(///2X17HINITIAL CONDITION,5X7HT(Z,0)=,F10.4,2H +,F10.4,5H *
   1Z +,F10.4,8H *Z**2 +,F10.4,6H *Z**3)
    GO TO 299

----------------------------------------------------------------------------------
I   T(Z,1)=A*SIN(Z*PIOL) + B*COS(Z*PI/L),                                        I
I   WHERE L IS ONE HALF PERIOD IN SPACE SCALE                                    I
----------------------------------------------------------------------------------

203 READ(5,12) AINI,BINI,HALFZ
    TIB=BINI
    DDZ=Z(1)/2.0
    DO 229 J=1,M
    ZPI=DDZ*3.14159/HALFZ
    T(J,1)=AINI*SIN(ZPI)+BINI*COS(ZPI)
229 DDZ=DDZ+Z(J)/2.0+Z(J+1)/2.0
    TBL(1)=AINI*SIN(ZPI)+BINI*COS(ZPI)
    WRITE(6,25) AINI,HALFZ,BINI,HALFZ
 25 FORMAT(///2X,17HINITIAL CONDITION,5X7HT(Z,0)=,F10.4,12H SIN(3.14*Z
   1/F5.2,3H) +,F10.4,12H COS(3.14*Z/F5.2,1H),)
    GO TO 299
```

```
------------------------------------------------------------------------------
I  STEP INITIAL CONDITION  T(Z,1)=A, Z=Z0 TO Z=Z1.      T(Z,1)=B,      I
(     Z=Z1 TO Z=Z2. ...  T(Z,1)=N, Z=Z(N-1) TO Z=ZN                    I
------------------------------------------------------------------------------

04 READ(5,11) NSTEP
   READ(5,12) (STEPA(I),STEPB(I),STEPT(I), I=1,NSTEP)
   TIB=STEPT(1)
   DDZ=Z(1)/2.0
   I=1
   DO 232 J=1,M
33 IF(DDZ.GE.STEPA(I).AND.DDZ.LT.STEPB(I)) GO TO 234
   I=I+1
   GO TO 23?
34 T(J,1)=STEPT(I)
32 DDZ=DDZ+Z(J)/2.0+Z(J+1)/2.0
   I=1
35 IF(DDZ.GE.STEPA(I).AND.DDZ.LT.STEPB(I)) GO TO 236
   I=I+1
   GO TO 235
36 TBL(1)=STEPT(I)
   WRITE(6,27)
27 FORMAT(///2X42HINITIAL CONDITION IN FORM OF STEP FUNCTION)
   WRITE(6,28)(STEPA(I),STEPB(I),STEPT(I),  I=1,NSTEP)
28 FORMAT(/7X7HFROM Z=,F10.4,6H TO Z=,F10.4,2X13HTEMPERATURE =,F10.4)
   GO TO 299

------------------------------------------------------------------------------
I  INITIAL CONDITION IS A SET OF DISCRETE NUMBERS                     I
------------------------------------------------------------------------------

05 CALL FIT(AINI,BINI,CINI,DINI)
   TIB=AINI
   DDZ=Z(1)/2.0
   DO 245 J=1,M
   T(J,1)=AINI+BINI*DDZ+CINI*DDZ**2+DINI*DDZ**3
45 DDZ=DDZ+Z(J)/2.0+Z(J+1)/2.0
   TBL(1)=AINI+BINI*DDZ+CINI*DDZ**2+DINI*DDZ**3
   WRITE(6,29) AINI,BINI,CINI,DINI
29 FORMAT(///2X46HINITIAL CONDITION BY CURVE FITTING AS  T(Z,0)=,
  1 F10.4,2H +,F10.4,5H *Z +,F10.4,8H *Z**2 +,F10.4,6H *Z**3)
   GO TO 299

------------------------------------------------------------------------------
I  TEMPERATURES AT CENTERS OF ALL SUBLAYERS GIVEN, (VALUES MAY BE     I
(    OBTAINED FROM PREVIOUS COMPUTATION)                              I
------------------------------------------------------------------------------

06 READ(5,10) TIB,(T(J,1), J=1,M),TBL(1)
   WRITE(6,30) TIB, (T(J,1), J=1,M)
30 FORMAT(///2X17HINITIAL CONDITION/5X102HTEMPERATURES AT CENTERS OF
  1ALL SUBLAYERS(DZ) GIVEN, (VALUES MAY BE OBTAINED FROM PREVIOUS COM
  2PUTATION)/15F6.1)
   GO TO 299

99 IF(TEMPI.EQ.CENT) GO TO 298
   TIB=(TIB-32.0)*5.0/9.0
   DO 297 J=1,M
```

```
97 T(J,1)=(T(J,1)-32.0)*5.0/9.0
   TBL(1)=(TBL(1)-32.0)*5.0/9.0


*************************************************************************
** TIME INCREMENT, DURATION OF FREEZING PERIOD                        ***
*************************************************************************

98 READ(5,13) THOUR,DT,DTOUT,TOTAL
   READ(5,15) JFOAM,DTFOAM
   WRITE(6,31) DT
31 FORMAT(/////2X23HINCREMENT OF TIME, DT =, F7.3,7H  HOURS)
   ITIME=DT*CELL/24.0
   TIME=ITIME*24
   IF(TIME.LT.24.0) TIME=DT*CELL
   TOUR=THOUR-TOTAL
   IF(TIME.GE.TOUR) TIME=TOUR
   LTIME=TOUR/TIME+0.99
   NDAY=TOUR/24.0
   TDAY=NDAY
   NHOUR=TOUR-TDAY*24.0

   WRITE(6,32) TOUR,NDAY,NHOUR
32 FORMAT(2X24HTOTAL DURATION OF TIME =,F7.1,8H HOURS =,I4,
  1  9H DAYS AND, I3,6H HOURS)

   KT=TIME/DT+1.0
   KTK=KT-1

*************************************************************************
**  BOUNDARY CONDITIONS, T(0,K) OR TB(K)  K=1,2,...                   **
**   READ 1 FOR CONSTANT                                               **
**        2 FOR ALGEBRAIC FUNCTION                                     **
**        3 FOR TRIGONOMETRIC FUNCTION                                 **
**        4 FOR STEP FUNCTION                                          **
**        5 FOR DATA TO BE FITTING INTO AN ALGBRAIC FUNCTION           **
*************************************************************************



   READ(5,11) IBOND
   GO TO (301,302,303,304,305), IBOND


-------------------------------------------------------------------------
   T(0,TIME)=CONSTANT FOR ALL THE TIME                                  I
-------------------------------------------------------------------------

301 READ(5,12) BOND
    DO 321 K=1,KT
321 TB(K)=BOND
    WRITE(6,33) BOND,TEMPB
33 FORMAT(//1X19HBOUNDARY CONDITIONS,9X53HTEMPERATURE AT BOUNDARY = C
  1ONSTANT FOR ALL THE TIME =,F10.4,8H DEGREE ,A4)
   GO TO 399


-------------------------------------------------------------------------
   T(0,TIME)=A+B*TIME+C*TIME**2+D*TIME**3                               I
-------------------------------------------------------------------------
```

```
2 READ(5,14) ABOND,BBOND,CBOND,DBOND,UNIT,START
  DDT=START
  DO 324 K=1,KT
  TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*(DDT/UNIT)**3
4 DDT=DDT+DT
  WRITE(6,34) ABOND,BBOND,CBOND,DBOND
4 FORMAT(//1X19HBOUNDARY CONDITIONS,5X10HT(0,TIME)=,F10.4,2H +,F10.4
 1,3H *TIME +,F10.4,11H *TIME**2 +,F10.4,9H *TIME**3)
  GO TO 399

--------------------------------------------------------------------------
  T(0,TIME)=A*SIN(PI*KT/T) + B*COS(PI*KT/T),                              I
    WHERE T IS ONE HALF PERIOD IN TIME SCALE,                             I
    KT IS THE TIME AT INTERVAL K                                          I
--------------------------------------------------------------------------

8 READ(5,14) ABOND,BBOND,UNIT,START,HALFT
  DDT=START
  DO 328 K=1,KT
  TPI=3.14159*(DDT/UNIT)/HALFT
  TB(K)=ABOND*SIN(TPI)+BBOND*COS( PI)
8 DDT=DDT+DT
  WRITE(6,35) ABOND,HALFT,BBOND,HALFT
5 FORMAT(///1X,18HBONDARY CONDITIONS,5X10HT(0,TIME)=,F10.4,12H SIN(3
 1.14*T/F5.2,3H) +,F10.4,12H COS(3.14*T/F5.2,1H),)
  GO TO 399

--------------------------------------------------------------------------
  STEP BOUNDARY CONDITION  T(0,TIME)=A, T=TO TO T=T1.  T(0,TIME)=B,I
     T=T1 TO T=T2. ... . T(0,TIME)=N, T=T(N-1) TO T=TN                   I
--------------------------------------------------------------------------

  READ(5,11) NSTEB
  READ(5,12) (STEBA(I),STEBB(I),STEBT(I), I=1,NSTEB)
  READ(5,12) UNIT,START
  DO 330 I=1,NSTEB
  STEBA(I)=STEBA(I)*UNIT
) STEBB(I)=STEBB(I)*UNIT
  WRITE(6,37)
7 FORMAT(///1X,44HBOUNDARY CONDITIONS IN FORM OF STEP FUNCTION//5X,
 1 10HNO OF STEP,9X20HTIME INTERVAL(HOURS),11X11HTEMPERATURE)
  WRITE(6,38)(I,STEBA(I),STEBB(I),STEBT(I),I=1,NSTEB)
8 FORMAT(I11,9XF10.3,3H - ,F10.3,10XF10.3)
  DDT=START
  I=1
  DO 331 K=1,KT
2 IF(DDT.GE.STEBA(I).AND.DDT.LE.STEBB(I)) GO TO 333
  I=I+1
  GO TO 332
3 TB(K)=STEBT(I)
1 DDT=DDT+DT
  GO TO 399

--------------------------------------------------------------------------
  BOUNDARY CONDITIONS IS A SET OF DISCRETE NUMBERS                        I
--------------------------------------------------------------------------

5 READ(5,12) UNIT,START
  CALL FIT(ABOND,BBOND,CBOND,DBOND)
```

```
   DDT=START
   DO 344 K=1,KT
   TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*(DDT/UNIT)**3
44 DDT=DDT+DT
   WRITE(6,40) ABOND,BBOND,CBOND,DBOND
40 FORMAT(///1X50HBOUNDARY CONDITION BY CURVE FITTING AS  T(0,TIME)=,
  1  F10.4,2H +,F10.4,8H *TIME +,F10.4,11H *TIME**2 +,F10.4,9H *TIME*
  2*3)
   GO TO 399

*****************************************************************************
** CORRECTION BOUNDARY VALUES FOR AIR-GROUND INTERFACE                     **
*****************************************************************************

99 READ(5,12) CORR
   DO 340 K=1,KT
   IF(TEMPB.EQ.CENT) TB(K)=TB(K)*9.0/5.0+32.0
   IF(TB(K).LE.32.0) TB(K)=32.0-(32.0-TB(K))*CORR
   IF(TB(K).GT.32.0) TB(K)=32.0+(TB(K)-32.0)*(2.0-CORR)
40 TB(K)=(TB(K)-32.0)*5.0/9.0
   WRITE(6,39) CORR
39 FORMAT(/ 1X64HCORRECTION FACTOR FOR BOUNDARY VALUES FOR AIR GROUND
  1 INTERFACE =, F6.3)

*****************************************************************************
** SPECIFY LOWER BOUNDARY CONDITION                                         **
**   READ 1 FOR CONSTANT                                                    **
**        2 FOR PERFECT INSULATION                                          **
**        3 FOR TEMPERATURE SAME AS BOUNDARY LAYER                          **
**        4 FOR SPECIFIED TEMPERATURE                                       **
*****************************************************************************

   READ(5,11) LBOND
   GO TO (351,352,353,354), LBOND

51 WRITE(6,41)
41 FORMAT(/1X,62HTEMPERATURE AT LOWER BOUNDARY REMAINS CONSTANT AT AL
  1L THE TIME)
   GO TO 1110
52 WRITE(6,42)
42 FORMAT(/1X124HASSUME THE LOWER BOUNDARY AS A PERFECT INSULATION TO
  1 THE HEAT FLOW, T(M+1,K)=T(M,K), WHERE LAYER (M+1) IS A FICTITIOUS
  2 LAYER)
   GO TO 1110
53 WRITE(6,43)
43 FORMAT(/1X,78HTEMPERATURE AT LOWER BOUNDARY IS SAME AS TEMPERATURE
  1 OF M LAYER, TBL(K)=T(M,K))
   GO TO 1110
54 READ(5,12) BONDL
   WRITE(6,44) BONDL,TEMPB
44 FORMAT(/1X,46HTEMP AT LOWER BDY EQUALS TO THE TEMP SPECIFIED,
  1  1H(,F6.2,1XA4,1H))
   IF(TEMPB.EQ.FAHR) BONDL=(BONDL-32.0)*5.0/9.0
   GO TO 1110

*****************************************************************************
** CALCULATING TEMPERATURES AT VARIOUS POINTS                               **
*****************************************************************************
```

```
110 DO 600 LLL=1,LTIME
    IF(LLL.EQ.1) GO TO 1112
    DO 1114 J=1,M
114 T(J,1)=T(J,KT)
    TBL(1)=TBL(KTK)

    REMAIN=THOUR-TOTAL
    IF(REMAIN.GT.TIME) GO TO 370
    TIME=REMAIN
    KT=TIME/DT+1.0
    KTK=KT-1
370 DDT=TOTAL
    GO TO (311,312,313,314,315), IBOND

311 DO 371 K=1,KT
371 TB(K)=BOND
    GO TO 398

312 DO 372 K=1,KT
    TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*(DDT/UNIT)**3
372 DDT=DDT+DT
    GO TO 398

313 DO 373 K=1,KT
    TPI=3.14159*(DDT/UNIT)/HALFT
    TB(K)=ABOND*SIN(TPI)+BBOND*COS(TPI)
373 DDT=DDT+DT
    GO TO 398

314 I=1
    DO 374 K=1,KT
384 IF(DDT.GE.STEBA(I).AND.DDT.LE.STEBB(I)) GO TO 385
    I=I+1
    GO TO 384
385 TB(K)=STEBT(I)
374 DDT=DDT+DT
    GO TO 398

315 DO 375 K=1,KT
    TB(K)=ABOND+BBOND*DDT/UNIT+CBOND*(DDT/UNIT)**2+DBOND*(DDT/UNIT)**3
375 DDT=DDT+DT
    GO TO 398

398 DO 397 K=1,KT
    IF(TEMPB.EQ.CENT) TB(K)=TB(K)*9.0/5.0+32.0
    IF(TB(K).LE.32.0) TB(K)=32.0-(32.0-TB(K))*CORR
    IF(TB(K).GT.32.0) TB(K)=32.0+(TB(K)-32.0)*(2.0-CORR)
397 TB(K)=(TB(K)-32.0)*5.0/9.0
    GO TO 1113

--------------------------------------------------------------------------------
I   TEMPERATURE IMMEDIATELY AFTER THE PROCESS STARTS IS TAKEN TO           I
I     BE THE AVERAGE  OF INITIAL AND BOUNDARY TEMPERATURES                 I
--------------------------------------------------------------------------------

112 TB(1)=(TIB+TB(1))/2.0

--------------------------------------------------------------------------------
I   WRITE INITIAL  TEMPERATURES                                            I
--------------------------------------------------------------------------------
```

```
13 WRITE(6,51) (J, J=1,M)

   I=0
   DTK=TOTAL
   IF(TEMPO.EQ.CENT) GO TO 481
   TIF=TB(1)*9.0/5.0+32.0
   DO 482 J=1,M
82 TF(J)=T(J,1)*9.0/5.0+32.0
   WRITE(6,52) I,DTK,TIF,(TF(J), J=1,M)
   GO TO 483
81 WRITE(6,52) I,DTK,TB(1), (T(J,1), J=1,M)




83 K=1
80 DO 501 J=1,M
   IF(WC(J).EQ.0.0) GO TO 502
   IF(T(J,K).GE.TFREZ) PARTF=0.0
   IF(T(J,K).LT.TFREZ) PARTF=(C5(J)-EXP(C6(J)*T(J,K)+C7(J)))/100.0
   GO TO 503
02 PARTF=0.0
03 PARTU=1.0-PARTF

----------------------------------------------------------------------------
I  COMPUTE VOLUMETRIC HEAT                                                  I
----------------------------------------------------------------------------

   SPHT(J)=VH(T(J,K),C1(J),C2(J),DEN(J),WC(J),PARTF,PARTU)

----------------------------------------------------------------------------
I  COMPUTE THERMAL CONDUCTIVITY                                             I
----------------------------------------------------------------------------

   COND(J)=TC(T(J,K),C3(J),C4(J),DEN(J),WC(J),PARTF,PARTU)

   CHECK STOP FOR NEGATIVE OR ZERO VOLUMETRIC HEAT AND THERMAL
     CONDUCTIVITY
   IF(SPHT(J).LE.0.0) GO TO 81
   IF(COND(J).LE.0.0) GO TO 82
   GO TO 501
81 WRITE(6,83) J
83 FORMAT(////,2X,45HNEGATIVE OR ZERO VOLUMETRIC HEAT, CHECK INPUT,
 1  1H(,I2,10H TH LAYER))
   STOP
82 WRITE(6,84) J
84 FORMAT(////,2X,50HNEGATIVE OR ZERO THERMAL CONDUCTIVITY, CHECK INP
 1UT,  1H(,I2,10H TH LAYER))
   STOP
01 CONTINUE

----------------------------------------------------------------------------
I  COMPUTE TEMP AT LOWER BOUNDARY ACCORDING TO SPECIFIED CONDITION          I
----------------------------------------------------------------------------

   IF(K.EQ.1) GO TO 411
   GO TO (451,452,453,454), LBOND

51 TBL(K)=TBL(1)
   GO TO 411
```

```
GO TO 411

TBL(K)=T(M,K)
GO TO 411

TBL(K)=BONDL
GO TO 411


---------------------------------------------*----------------------------------------------
COMPUTE TEMP BY CALLING CORRESPONDING SUBROUTINE ACCORDING TO      I
  CALCULATED DISCRIMINANT                                          I
---------------------------------------------*----------------------------------------------

J=1
IF(J.EQ.1) GO TO 401
IF(J.GE.2.OR.J.LT.M) GO TO 402
IF(J.EQ.M) GO TO 403

T32=(T(2,K)-T(1,K))/(Z(2)/COND(2)+Z(1)/COND(1))
T21=(T(1,K)-TB(K))/(Z(1)/COND(1))
GO TO 404

T32=(T(J+1,K)-T(J,K))/(Z(J+1)/COND(J+1)+Z(J)/COND(J))
T21=(T(J,K)-T(J-1,K))/(Z(J)/COND(J)+Z(J-1)/COND(J-1))
GO TO 404

IF(LBOND.EQ.2) TBL(K)=T(M,K)
T32=(TBL(K)-T(M,K))/(Z(M)/COND(M))
T21=(T(M,K)-T(M-1,K))/(Z(M)/COND(M)+Z(M-1)/COND(M-1))
GO TO 404

D=T32-T21
IF(J.EQ.JFOAM) GO TO 406
IF(D.GT.0.0) GO TO 407
IF(D.LT.0.0) GO TO 408
T(J,K+1)=T(J,K)
GO TO 410

CALL STYRO(TT)
T(J,K+1)=TT
GO TO 410

TJK=T(J,K)
CALL WARM(DT,TJK,TT)
T(J,K+1)=TT
GO TO 410

TJK=T(J,K)
CALL COOL(DT,TJK,TT)
T(J,K+1)=TT
GO TO 410

IF(J.GE.M) GO TO 420
J=J+1
GO TO 400

***************************************************************************
 WRITE OUTPUT                                                          ***
***************************************************************************
```

```
20 DTK=DTK+DT
   IF(DTK.LT.DTOUT) GO TO 423
   OUT1=DTK/DTOUT
   LOUT=DTK/DTOUT+0.01
   OUT2=LOUT
   DIFF=OUT1-OUT2
   IF(ABS(DIFF).GT.0.0001) GO TO 423
   IF(TEMPO.EQ.CENT) GO TO 421
   TBF=TB(K+1)*9.0/5.0+32.0
   DO 422 J=1,M
22 TF(J)=T(J,K+1)*9.0/5.0+32.0
   WRITE(6,52) K,DTK,TBF, (TF(J), J=1,M)
   GO TO 423
21 WRITE(6,52) K,DTK,TB(K+1), (T(J,K+1), J=1,M)
23 IF(K.GE.KTK) GO TO 601
   K=K+1
   GO TO 480
51 FORMAT(1H1,13H T/Z ACC TIME,3X3HBDY,2X,15I6)
52 FORMAT(I4,F8.2,3XF6.2,3X15F6.2)


01 TOTAL=TOTAL+TIME
   WRITE(6,53) TOTAL,DT
53 FORMAT(/3X23HTHE TIME AT LAST STEP =,F8.2, 6H HOURS,3X,
 1   16H(TIME INCREMENT=, F5.2,7H HOURS))

00 CONTINUE

----------------------------------------------------------------------
   FORMAT FOR INPUT                                                  I
----------------------------------------------------------------------
 9 FORMAT(18A4)
10 FORMAT(2XA3,6XA4,6XA4,6XA4,6XA4)
11 FORMAT(I5)
12 FORMAT(3F10.4)
13 FORMAT(4F10.4)
14 FORMAT(6F10.4)
15 FORMAT(I5,F10.4)

***********************************************************************
   GO TO 800
   END

***********************************************************************

TC SUB1
   SUBROUTINE CURVE(C,AA,BB,ICORF)
   DIMENSION X(15),Y(15),A(100),B(100)
   READ(5,11) N
   P=0.000001
   READ(5,12) (X(I),Y(I), I=1,N)
   READ(5,12) C
   GO TO (1,2), ICORF
 1 A(1)=0.5
   B(1)=4.0
   GO TO 3
 2 A(1)=0.25
   B(1)=-4.0
 3 K=1
00 F=0.
   G=0.
```

```
  FA=0.
  FB=0.
  GA=0.
  GB=0.
  DO 101 I=1,N
  E=EXP(A(K)*X(I)+B(K))
  F=F+(Y(I)-C+E)*(X(I)*E)
  G=G+(Y(I)-C+E)*E
  FA=FA+X(I)*(X(I)*Y(I)*E-X(I)*E*C+2.0*X(I)*E**2)
  FB=FB+X(I)*(Y(I)*E-C*E+2.0*E**2)
  GA=FB
1 GB=GB+(Y(I)*E-C*E+2.0*E**2)
  D=FA*GB-FB*GA
  DELTA=(G*FB-F*GB)/D
  EPSI=(F*GA-G*FA)/D
  A(K+1)=A(K)+DELTA
  B(K+1)=B(K)+EPSI
  ERRA=ABS(A(K+1)-A(K))
  ERRB=ABS(B(K+1)-B(K))
  IF(ERRA.LE.P.AND.ERRB.LE.P) GO TO 102
3 K=K+1
  GO TO 100
2 KK=K+1
  AA=A(KK)
  BB=B(KK)
1 FORMAT(I5)
2 FORMAT(2F10.4)
  RETURN
  END

TC SUB2
  SUBROUTINE FIT(A,B,C,D)

  FITTING CURVE BY LEAST SQUARE AND GAUSS-SIEDEL METHOD

  DIMENSION S(10),X(365),Y(365)
  READ(5,11) N
  READ(5,12) (X(I),Y(I), I=1,N)
  DO 1 M=1,10
1 S(M)=0.

  DO 2 I=1,N
  S(1)=S(1)+Y(I)
  S(2)=S(2)+X(I)*Y(I)
  S(3)=S(3)+X(I)**2*Y(I)
  S(4)=S(4)+X(I)**3*Y(I)
  S(5)=S(5)+X(I)
  S(6)=S(6)+X(I)**2
  S(7)=S(7)+X(I)**3
  S(8)=S(8)+X(I)**4
  S(9)=S(9)+X(I)**5
2 S(10)=S(10)+X(I)**6

  GAUSS-SIEDEL METHOD - SOLVE LINEAR SYSTEM

  FN=N
  A=S(1)/FN
  B=S(2)/S(6)
  C=S(3)/S(8)
  D=S(4)/S(10)
```

```
P=0.0001
AA=A
BB=B
CC=C
DD=D
A=(S(1)-B*S(5)-C*S(6)-D*S(7))/FN
B=(S(2)-A*S(5)-C*S(7)-D*S(8))/S(6)
C=(S(3)-A*S(6)-B*S(7)-D*S(9))/S(8)
D=(S(4)-A*S(7)-B*S(8)-C*S(9))/S(10)

IF(ABS(A-AA).GT.P) GO TO 3
IF(ABS(B-BB).GT.P) GO TO 3
IF(ABS(C-CC).GT.P) GO TO 3
IF(ABS(D-DD).GT.P) GO TO 3

FORMAT(I5)
FORMAT(2F10.4)

RETURN
END

 SUB3
SUBROUTINE COOL(DT,TJK,TT)

************************************************************************
TEMPERATURE AT (K+1)TH TIME INTERVAL WILL BE LESS THAN (K)TH INT.
************************************************************************
DIMENSION Z(15),DEN(15),WC(15),SPHT(15),COND(15),T(16,500)
DIMENSION C1(15),C2(15),C3(15),C4(15),C5(15),C6(15),C7(15)
DIMENSION TB(999),TBL(999)
COMMON C1,C2,C3,C4,C5,C6,C7,T,SPHT,COND,DEN,WC,J,K,M,Z,D
     ,TB,TBL,DTFOAM,JFOAM,LBOND
DATA TFREZ,P/0.0,0.001/,QL/80.0/

IF(J.EQ.1) GO TO 110
IF(J.LT.M) GO TO 120
IF(J.EQ.M) GO TO 130

------------------------------------------------------------------------
UPPER BOUNDARY LAYER
------------------------------------------------------------------------

IF(WC(1).EQ.0.0) GO TO 112
IF(TJK.LE.TFREZ) GO TO 117
DTF=SPHT(1)*Z(1)*(TFREZ-TJK)/(2.0*D)
IF(DTF-DT) 113,111,112

TT=TFREZ
RETURN

AB1=2.0*DT/SPHT(1)/Z(1)
AB2=Z(2)/COND(2)
AB3=Z(1)/COND(1)
B=AB1/AB3
A=AB1/(AB2+AB3)
TT=A*T(2,K)-(A+B-1.0)*TJK+B*TB(K)
RETURN

DT2=DT
TT=TJK-100.0*P
GO TO 114
```

```
13 DT2=DT-DTF
   TJK=TFREZ
   TT=TFREZ-100.0*P

14 AB1=2.0*DT2/SPHT(1)/Z(1)
   AB2=Z(2)/COND(2)
   AB3=Z(1)/COND(1)
   B=AB1/AB3
   A=AB1/(AB2+AB3)
   TAB=A*T(2,K)-(A+B-1.0)*TJK+B*TB(K)
   HL=QL*DEN(1)*WC(1)/SPHT(1)/100.0
   EXPK=EXP(C6(1)*TJK+C7(1))/100.0
15 EXPK1=EXP(C6(1)*TT+C7(1))/100.0
   TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(1)*EXPK1)
   IF(ABS(TTT-TT).LE.P) GO TO 40
16 TT=TTT
   GO TO 115

-------------------------------------------------------------------------
   INTERMEDIATE LAYER
-------------------------------------------------------------------------

20 IF(WC(J).EQ.0.0) GO TO 122
   IF(TJK.LE.TFREZ) GO TO 127
   DTF=SPHT(J)*Z(J)*(TFREZ-TJK)/(2.0*D)
   IF(DTF-DT) 123,121,122

21 TT=TFREZ
   RETURN

22 AB1=2.0*DT/SPHT(J)/Z(J)
   AB2=Z(J+1)/COND(J+1)
   AB3=Z(J)/COND(J)
   AB4=Z(J-1)/COND(J-1)
   B=AB1/(AB3+AB4)
   A=AB1/(AB2+AB3)
   TT=A*T(J+1,K)-(A+B-1.0)*TJK+B*T(J-1,K)
   RETURN

27 DT2=DT
   TT=TJK-100.0*P
   GO TO 124

23 DT2=DT-DTF
   TJK=TFREZ
   TT=TFREZ-100.0*P

24 AB1=2.0*DT2/SPHT(J)/Z(J)
   AB2=Z(J+1)/COND(J+1)
   AB3=Z(J)/COND(J)
   AB4=Z(J-1)/COND(J-1)
   B=AB1/(AB3+AB4)
   A=AB1/(AB2+AB3)
   TAB=A*T(J+1,K)-(A+B-1.0)*TJK+B*T(J-1,K)
   HL=QL*DEN(J)*WC(J)/SPHT(J)/100.0
   EXPK=EXP(C6(J)*TJK+C7(J))/100.0
25 EXPK1=EXP(C6(J)*TT+C7(J))/100.0
   TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(J)*EXPK1)
   IF(ABS(TTT-TT).LE.P) GO TO 40
```

```
TT=TTT
GO TO 125
```

LOWER BOUNDARY LAYER

```
IF(WC(M).EQ.0.0) GO TO 132
IF(TJK.LE.TFREZ) GO TO 137
DTF=SPHT(M)*Z(M)*(TFREZ-TJK)/(2.0*D)
IF(DTF-DT) 133,131,132

TT=TFREZ
RETURN

AB1=2.0*DT/SPHT(M)/Z(M)
AB2=Z(M)/COND(M)
AB3=Z(M-1)/COND(M-1)
B=AB1/(AB2+AB3)
IF(LBOND.EQ.2) GO TO 138
A=AB1/AB2
GO TO 144
A=AB1/(2.0*AB2)
TBL(K)=TJK
TT=A*TBL(K)-(A+B-1.0)*TJK+B*T(M-1,K)
RETURN

DT2=DT
TT=TJK-100.0*P
GO TO 134

DT2=DT-DTF
TJK=TFREZ
TT=TFREZ-100.0*P

AB1=2.0*DT2/SPHT(M)/Z(M)
AB2=Z(M)/COND(M)
AB3=Z(M-1)/COND(M-1)
B=AB1/(AB2+AB3)
IF(LBOND.EQ.2) GO TO 139
A=AB1/AB2
GO TO 140
A=AB1/(2.0*AB2)
TBL(K)=T(M,K)
TAB=A*TBL(K)-(A+B-1.0)*TJK+B*T(M-1,K)
HL=QL*DEN(M)*WC(M)/SPHT(M)/100.0
EXPK=EXP(C6(M)*TJK+C7(M))/100.0
EXPK1=EXP(C6(M)*TT+C7(M))/100.0
TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(M)*EXPK1)
IF(ABS(TTT-TT).LE.P) GO TO 40
TT=TTT
GO TO 135

RETURN
END

C SUB4
SUBROUTINE WARM(DT,TJK,TT)
```

****

```
TEMP AT (K+1)TH TIME INTERVAL WILL BE HIGHER THAN (K)TH TIME INT.
*******************************************************************
DIMENSION Z(15),DEN(15),WC(15),SPHT(15),COND(15),T(16,500)
DIMENSION C1(15),C2(15),C3(15),C4(15),C5(15),C6(15),C7(15)
DIMENSION TB(999),TBL(999)
COMMON C1,C2,C3,C4,C5,C6,C7,T,SPHT,COND,DEN,WC,J,K,M,Z,D
     ,TB,TBL,DTFOAM,JFOAM,LBOND
DATA TFREZ,P/0.0,0.001/,QL/80.0/

IF(J.EQ.1) GO TO 110
IF(J.LT.M) GO TO 120
IF(J.EQ.M) GO TO 130

-------------------------------------------------------------------
UPPER BOUNDARY LAYER
-------------------------------------------------------------------

IF(WC(1).EQ.0.0) GO TO 117
IF(TJK.GE.TFREZ) GO TO 117
HL=QL*DEN(1)*WC(1)/SPHT(1)/100.0
EXP1=(C5(1)-EXP(C6(1)*TJK+C7(1)))/100.0
DTF=SPHT(1)*Z(1)*(TFREZ-TJK+HL*EXP1)/(2.0*D)
IF(DTF-DT) 112,111,113

TT=TFREZ
RETURN

DT2=DT
GO TO 118
DT2=DT-DTF
TJK=TFREZ
AB1=2.0*DT2/SPHT(1)/Z(1)
AB2=Z(2)/COND(2)
AB3=Z(1)/COND(1)
B=AB1/AB3
A=AB1/(AB2+AB3)
TT=A*T(2,K)-(A+B-1.0)*TJK+B*TB(K)
RETURN

AB1=2.0*DT/SPHT(1)/Z(1)
AB2=Z(2)/COND(2)
AB3=Z(1)/COND(1)
B=AB1/AB3
A=AB1/(AB2+AB3)
TAB=A*T(2,K)-(A+B-1.0)*TJK+B*TB(K)
EXPK=EXP(C6(1)*TJK+C7(1))/100.0
TT=TJK-100.0*P

EXPK1=EXP(C6(1)*TT+C7(1))/100.0
TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(1)*EXPK1)
IF(ABS(TTT-TT).LE.P) GO TO 40
TT=TTT
GO TO 115

-------------------------------------------------------------------
INTERMEDIATE LAYER
-------------------------------------------------------------------

IF(WC(J).EQ.0.0) GO TO 127
IF(TJK.GE.TFREZ) GO TO 127
HL=QL*DEN(J)*WC(J)/SPHT(J)/100.0
```

```
      EXPJ=(C5(J)-EXP(C6(J)*TJK+C7(1)))/100.0
      DTF=SPHT(J)*Z(J)*(TFREZ-TJK+HL*EXPJ)/(2.0*D)
      IF(DTF-DT) 122,121,123

      TT=TFREZ
      RETURN

      DT2=DT
      GO TO 128
      DT2=DT-DTF
      TJK=TFREZ
      AB1=2.0*DT2/SPHT(J)/Z(J)
      AB2=Z(J+1)/COND(J+1)
      AB3=Z(J)/COND(J)
      AB4=Z(J-1)/COND(J-1)
      B=AB1/(AB3+AB4)
      A=AB1/(AB2+AB3)
      TT=A*T(J+1,K)-(A+B-1.0)*TJK+B*T(J-1,K)
      RETURN

      AB1=2.0*DT/SPHT(J)/Z(J)
      AB2=Z(J+1)/COND(J+1)
      AB3=Z(J)/COND(J)
      AB4=Z(J-1)/COND(J-1)
      B=AB1/(AB3+AB4)
      A=AB1/(AB2+AB3)
      TAB=A*T(J+1,K)-(A+B-1.0)*TJK+B*T(J-1,K)
      EXPK=EXP(C6(J)*TJK+C7(J))/100.0
      TT=TJK-100.0*P

      EXPK1=EXP(C6(J)*TT+C7(J))/100.0
      TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(J)*EXPK1)
      IF(ABS(TTT-TT).LE.P) GO TO 40
      TT=TTT
      GO TO 125

------------------------------------------------------------------------
      LOWER BOUNDARY LAYER
------------------------------------------------------------------------

      IF(WC(M).EQ.0.0) GO TO 137
      IF(TJK.GE.TFREZ) GO TO 137
      HL=QL*DEN(M)*WC(M)/SPHT(M)/100.0
      EXPM=(C5(M)-EXP(C6(M)*TJK+C7(1)))/100.0
      DTF=SPHT(M)*Z(M)*(TFREZ-TJK+HL*EXPM)/(2.0*D)
      IF(DTF-DT) 132,131,133

      TT=TFREZ
      RETURN

      DT2=DT
      GO TO 138
      DT2=DT-DTF
      TJK=TFREZ

      AB1=2.0*DT2/SPHT(M)/Z(M)
      AB2=Z(M)/COND(M)
      AB3=Z(M-1)/COND(M-1)
      B=AB1/(AB2+AB3)
      IF(LBOND.EQ.2) GO TO 139
      A=AB1/AB2
```

```
GO TO 140
A=AB1/(2.0*AB2)
TBL(K)=TJK
TT=A*TBL(K)-(A+B-1.0)*TJK+B*T(M-1,K)
RETURN

AB1=2.0*DT/SPHT(M)/Z(M)
AB2=Z(M)/COND(M)
AB3=Z(M-1)/COND(M-1)
B=AB1/(AB2+AB3)
IF(LBOND.EQ.2) GO TO 141
A=AB1/AB2
GO TO 142
A=AB1/(2.0*AB2)
TBL(K)=TJK
TAB=A*TBL(K)-(A+B-1.0)*TJK+B*T(M-1,K)
EXPK=EXP(C6(M)*TJK+C7(M))/100.0
TT=TJK-100.0*P

EXPK1=EXP(C6(M)*TT+C7(M))/100.0
TTT=TT-(TT-TAB+HL*(EXPK1-EXPK))/(1.0+HL*C6(M)*EXPK1)
IF(ABS(TTT-TT).LE.P) GO TO 40
TT=TTT
GO TO 135

RETURN
END

 SUB5
SUBROUTINE STYRO(TT)

*************************************************************************
COMPUTE TEMPERATURE FOR EXTRA THIN LAYER WHICH NEEDS MORE STEPS **
  TO MEET STABILITY REQUIREMENT THAN OTHER LAYERS                 **
*************************************************************************
DIMENSION Z(15),DEN(15),WC(15),SPHT(15),COND(15),T(16,500)
DIMENSION C1(15),C2(15),C3(15),C4(15),C5(15),C6(15),C7(15)
DIMENSION TB(999),TBL(999)
COMMON C1,C2,C3,C4,C5,C6,C7,T,SPHT,COND,DEN,WC,J,K,M,Z,D
     ,TB,TBL,DTFOAM,JFOAM,LBOND

IF(D.NE.0.0) GO TO 10
TT=T(J,K)
RETURN

NDT=DT/DTFOAM+0.0001

IF(JFOAM.EQ.1) GO TO 110
IF(JFOAM.LT.M) GO TO 120
IF(JFOAM.EQ.M) GO TO 130

-------------------------------------------------------------------------
UPPER BOUNDARY LAYER
-------------------------------------------------------------------------

AB1=2.0*DTFOAM/SPHT(1)/Z(1)
AB2=Z(2)/COND(2)
AB3=Z(1)/COND(1)
B=AB1/AB3
A=AB1/(AB2+AB3)
TT=T(1,K)
```

```
      DO 111 NFOAM=1,NDT
  111 TT=A*T(2,K)-(A+B-1.0)*TT+B*TB(K)
      RETURN
C
C
C-----------------------------------------------------------------------
C     INTERMEDIATE LAYER
C-----------------------------------------------------------------------
C
  120 AB1=2.0*DTFOAM/SPHT(J)/Z(J)
      AB2=Z(J+1)/COND(J+1)
      AB3=Z(J)/COND(J)
      AB4=Z(J-1)/COND(J-1)
      B=AB1/(AB3+AB4)
      A=AB1/(AB2+AB3)
      TT=T(J,K)
      DO 121 NFOAM=1,NDT
  121 TT=A*T(J+1,K)-(A+B-1.0)*TT+B*T(J-1,K)
      RETURN
C
C
C-----------------------------------------------------------------------
C     LOWER BOUNDARY LAYER
C-----------------------------------------------------------------------
C
  130 AB1=2.0*DTFOAM/SPHT(M)/Z(M)
      AB2=Z(M)/COND(M)
      AB3=Z(M-1)/COND(M-1)
      B=AB1/(AB2+AB3)
      IF(LBOND.EQ.2) GO TO 132
      A=AB1/AB2
      GO TO 133
  132 A=AB1/(2.0*AB2)
  133 TT=T(M,K)
      TBL(K)=T(M,K)
      DO 131 NFOAM=1,NDT
  131 TT=A*TBL(K)-(A+B-1.0)*TT+B*T(M-1,K)
      RETURN
C
C
      END
*DECK SUB6
      FUNCTION VH(T,A,B,DEN,WC,PARTF,PARTU)
C***********************************************************************
C*    THIS SUBPROGRAM IS WRITTEN FOR COMPUTING VOLUMETRIC HEAT OF     **
C*     THE LAYER AT SPECIFIED TEMPERATURE AND AMOUNT OF WATER FROZEN  **
C***********************************************************************
C
      DATA SPHTW,SPHTI/1.0,0.49/
C
      IF(WC.EQ.0.0) GO TO 1
      VH=A*T+B+DEN*(WC/100.0)*(SPHTW*PARTU+SPHTI*PARTF)
      RETURN
C
    1 VH=A*T+B
      RETURN
C
      END
C
*DECK SUB7
```

```
FUNCTION TC(T,A,B,DEN,WC,PARTF,PARTU)
*************************************************************************
* THIS SUBPROGRAM IS WRITTEN FOR COMPUTING THERMAL CONDUCTIVITY      **
*   OF THE LAYER AT SPECIFIED TEMPERATURE AND AMOUNT OF WATER        **
*   FROZEN                                                           **
*************************************************************************

DATA TCW,TCI/0.514,1.91/,SPWT/2.65/

IF(WC.EQ.0.0) GO TO 1
C=DEN/SPWT
D=DEN*WC/100.0

TC=C/(C+D)*(A*T+B)+D/(C+D)*(TCI*PARTF+TCW*PARTU)
RETURN

TC=A*T+B
RETURN

END
```

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	0.	45.04	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
24	12.00	40.08	42.63	45.73	47.23	48.11	48.34	49.18	49.90	49.98	50.00	50.00	50.00	50.00
48	24.0	40.08	41.80	43.96	45.06	45.77	46.02	47.81	49.55	49.79	49.95	49.99	50.00	50.00
72	36.00	41.09	42.06	43.31	43.98	44.48	44.70	46.94	49.18	49.52	49.83	49.97	50.00	50.00
96	48.00	41.09	41.84	42.82	43.35	43.78	43.99	46.42	48.86	49.26	49.67	49.92	49.99	50.00
120	60.00	40.08	40.95	42.07	42.67	43.14	43.38	45.97	48.59	49.01	49.50	49.85	49.98	50.00
144	72.00	40.08	40.77	41.68	42.18	42.61	42.84	45.56	48.32	48.77	49.32	49.76	49.97	50.00
168	84.00	41.09	41.41	41.86	42.15	42.44	42.65	45.34	48.09	48.55	49.14	49.66	49.94	50.00
192	96.00	41.09	41.42	41.88	42.16	42.45	42.65	45.25	47.91	48.36	48.98	49.55	49.92	49.99
216	108.00	35.03	36.93	39.30	40.51	41.33	41.66	44.63	47.70	48.19	48.82	49.44	49.88	49.99
240	120.00	35.03	36.42	38.20	39.15	39.87	40.21	43.78	47.35	47.94	48.66	49.33	49.84	49.98
264	132.00	38.06	39.36	38.81	39.14	39.50	39.76	43.36	47.03	47.65	48.46	49.21	49.80	49.97
288	144.00	38.06	39.42	38.93	39.26	39.62	39.87	43.31	46.81	47.42	48.26	49.08	49.75	49.96
312	156.00	39.07	39.19	39.42	39.61	39.87	40.10	43.33	46.65	47.23	48.07	48.95	49.69	49.95
336	168.0	39.07	39.29	39.62	39.86	40.14	40.36	43.41	46.53	47.08	47.91	48.82	49.63	49.94
360	180.00	44.12	42.09	41.89	41.33	41.24	41.33	43.84	46.43	46.97	47.77	48.69	49.57	49.92
384	192.00	44.12	42.55	42.87	42.59	42.52	42.61	44.54	46.57	46.96	47.68	48.58	49.51	49.91
408	204.00	37.05	39.58	40.46	41.40	42.03	42.27	44.45	46.61	46.98	47.62	48.48	49.44	49.89
432	216.00	37.05	39.15	39.55	40.30	40.85	41.11	43.78	46.45	46.91	47.57	48.40	49.38	49.87
456	228.0	40.08	40.14	40.20	40.44	40.64	40.85	43.54	46.29	46.77	47.49	48.32	49.31	49.86
480	240.0	40.08	40.24	40.50	40.68	40.91	41.09	43.61	46.21	46.67	47.39	48.24	49.25	49.84

THE TIME AT LAST STEP = 240.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/2	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	240.00	40.08	40.24	40.50	40.68	40.91	41.09	43.61	46.21	46.67	47.39	48.24	49.25	49.84
24	252.00	38.06	39.80	39.75	40.27	40.69	40.91	43.50	46.13	46.59	47.30	48.17	49.20	49.82
48	264.00	38.06	39.66	39.45	39.91	40.30	40.52	43.24	46.00	46.49	47.21	48.09	49.14	49.80
72	276.00	39.06	39.58	39.27	39.68	40.04	40.26	43.05	45.88	46.37	47.12	48.01	49.08	49.78
96	288.00	38.06	39.52	39.15	39.53	39.88	40.09	42.90	45.76	46.26	47.02	47.93	49.02	49.76
120	300.00	39.07	39.24	39.50	39.70	39.95	40.14	42.87	45.66	46.15	46.92	47.85	48.97	49.74
144	312.00	39.07	39.30	39.63	39.86	40.12	40.30	42.92	45.59	46.07	46.83	47.77	48.91	49.72
168	324.00	42.10	41.58	41.00	40.78	40.77	40.89	43.18	45.56	46.01	46.75	47.69	48.86	49.70
192	336.00	42.10	41.85	41.59	41.50	41.55	41.66	43.60	45.62	46.00	46.69	47.62	48.80	49.68
216	348.00	44.12	43.51	42.80	42.50	42.41	42.47	44.05	45.71	46.03	46.67	47.56	48.75	49.66
240	360.00	44.12	43.78	43.39	43.23	43.20	43.25	44.51	45.83	46.10	46.66	47.51	48.70	49.64
264	372.00	50.18	48.43	46.33	45.34	44.81	44.73	45.31	46.02	46.20	46.69	47.47	48.65	49.62
288	384.00	50.18	49.05	47.65	46.96	46.56	46.47	46.37	46.34	46.40	46.75	47.45	48.60	49.61
312	396.00	44.12	44.93	45.88	46.32	46.56	46.61	46.62	46.60	46.62	46.86	47.46	48.57	49.59
336	408.00	44.12	44.64	45.29	45.62	45.83	45.89	46.29	46.67	46.75	46.97	47.49	48.53	49.57
360	420.00	35.03	37.76	41.09	42.71	43.68	43.97	45.34	46.60	46.79	47.04	47.52	48.51	49.56
384	432.00	35.03	36.89	39.24	40.44	41.24	41.54	43.94	46.28	46.64	47.05	47.55	48.49	49.54
408	444.00	36.04	37.13	38.54	39.31	39.89	40.16	43.04	45.94	46.41	46.97	47.55	48.48	49.53
432	456.00	36.04	36.90	38.02	38.64	39.15	39.42	42.52	45.65	46.17	46.84	47.53	48.46	49.52
456	468.00	35.03	36.00	37.26	37.94	38.49	38.78	42.07	45.39	45.95	46.69	47.47	48.45	49.51
480	480.00	35.03	35.82	36.86	37.45	37.95	38.23	41.66	45.14	45.73	46.54	47.40	48.43	49.50

THE TIME AT LAST STEP = 480.00 HOURS (TIME INCREMENT= 0.50 HOURS)

I/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	480.00	35.03	35.82	36.86	37.45	37.95	38.23	41.66	45.14	45.73	46.54	47.40	48.43	49.50
24	492.00	41.09	40.19	39.18	38.78	38.71	38.85	41.85	44.97	45.54	46.39	47.32	48.40	49.49
48	504.00	41.09	40.65	40.11	39.91	39.92	40.04	42.47	44.99	45.46	46.26	47.23	48.37	49.48
72	516.00	41.09	40.88	40.66	40.61	40.68	40.80	42.88	45.05	45.46	46.19	47.15	48.34	49.48
96	528.00	41.09	41.04	41.01	41.04	41.15	41.26	43.16	45.11	45.48	46.15	47.08	48.30	49.47
120	540.00	31.01	33.67	36.93	38.55	39.57	39.93	42.53	45.06	45.43	46.13	47.02	48.27	49.46
144	552.00	31.01	32.87	35.24	36.48	37.36	37.73	41.25	44.74	45.32	46.07	46.97	48.23	49.44
168	564.00	38.06	37.63	37.22	37.13	37.26	37.46	40.90	44.45	45.07	45.94	46.92	48.19	49.43
192	576.00	36.06	37.94	37.85	37.88	38.04	38.23	41.25	44.36	44.93	45.81	46.84	48.16	49.42
216	588.00	35.03	35.86	36.42	37.51	37.98	38.23	41.25	44.31	44.85	45.70	46.76	48.12	49.41
240	600.00	35.03	35.71	36.60	37.11	37.56	37.81	40.97	44.18	44.75	45.61	46.69	48.08	49.40
264	612.00	36.04	34.36	35.83	37.14	37.47	37.70	40.65	44.06	44.63	45.52	46.61	48.04	49.39
288	624.00	36.04	34.39	36.39	37.20	37.53	37.76	40.83	43.97	44.53	45.42	46.53	47.99	49.37
312	636.00	38.06	37.90	37.78	37.79	37.94	38.12	40.97	43.94	44.46	45.34	46.46	47.95	49.36
336	648.00	38.06	38.08	38.15	38.25	38.44	38.61	41.23	43.92	44.42	45.27	46.39	47.90	49.35
360	660.00	39.07	38.33	38.81	38.81	38.93	39.08	41.47	43.94	44.41	45.22	46.32	47.86	49.33
384	672.00	39.07	39.08	39.13	39.21	39.36	39.51	41.72	43.99	44.42	45.19	46.27	47.81	49.32
408	684.00	41.09	40.66	40.19	40.01	40.01	40.10	42.04	44.05	44.44	45.17	46.22	47.77	49.30
432	696.00	41.09	40.83	40.68	40.61	40.66	40.75	42.42	44.16	44.50	45.17	46.19	47.73	49.29
456	708.00	46.14	44.77	43.12	42.37	42.00	41.97	43.09	44.31	44.59	45.20	46.16	47.69	49.28
480	720.00	46.14	45.28	44.22	43.72	43.46	43.43	43.97	44.58	44.75	45.25	46.15	47.66	49.26

THE TIME AT LAST STEP = 720.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	720.00	46.14	45.28	44.22	43.72	43.46	43.43	43.97	44.58	44.75	45.25	46.15	47.66	49.26
24	732.00	46.14	45.58	44.90	44.57	44.33	44.36	44.58	44.85	44.95	45.35	46.16	47.63	49.25
48	744.00	46.14	45.77	45.32	45.10	44.98	44.95	45.01	45.09	45.15	45.47	46.19	47.61	49.24
72	756.00	44.12	44.40	44.73	44.89	44.98	45.01	45.15	45.28	45.34	45.60	46.23	47.59	49.23
96	768.00	44.12	44.31	44.54	44.66	44.75	44.78	45.09	45.39	45.47	45.71	46.29	47.58	49.22
120	780.00	44.12	44.26	44.44	44.53	44.61	44.65	45.05	45.47	45.56	45.81	46.35	47.58	49.21
144	792.00	44.12	44.23	44.38	44.46	44.53	44.57	45.05	45.53	45.64	45.89	46.40	47.58	49.20
168	804.00	42.10	42.72	43.48	43.86	44.11	44.20	44.89	45.57	45.70	45.95	46.46	47.58	49.19
192	816.00	42.10	42.54	43.10	43.39	43.61	43.70	44.62	45.55	45.71	46.00	46.51	47.59	49.19
216	828.00	44.12	42.93	43.73	43.66	43.66	43.71	44.61	45.54	45.71	46.03	46.55	47.61	49.19
240	840.00	44.12	44.04	43.95	43.92	43.95	43.99	44.77	45.58	45.74	46.06	46.58	47.62	49.19
264	852.00	29.03	32.92	37.66	39.97	41.34	41.74	43.69	45.49	45.75	46.08	46.61	47.63	49.19
288	864.00	29.03	31.68	35.02	36.73	37.87	38.30	41.69	45.01	45.52	46.05	46.63	47.65	49.19
312	876.00	23.09	26.76	31.63	33.40	34.68	35.20	39.84	44.43	45.14	45.90	46.62	47.66	49.19
336	888.00	23.09	26.18	30.25	31.89	32.75	33.21	38.48	43.80	44.67	45.67	46.57	47.67	49.19
360	900.00	25.07	27.10	29.85	31.27	32.03	32.47	37.85	43.31	44.22	45.38	46.47	47.67	49.19
384	912.00	25.07	26.96	29.51	30.84	31.76	32.18	37.50	42.92	43.84	45.09	46.34	47.66	49.19
408	924.00	26.06	27.48	29.43	30.55	31.46	31.93	37.21	42.59	43.52	44.82	46.19	47.63	49.19
432	936.00	26.05	27.43	29.30	30.35	31.24	31.70	36.95	42.30	43.23	44.57	46.03	47.60	49.19
456	948.00	15.17	20.08	26.44	29.33	30.84	31.40	36.68	42.04	42.97	44.34	45.87	47.56	49.19
480	960.00	15.17	19.36	24.92	27.84	29.82	30.55	36.12	41.75	42.72	44.12	45.71	47.50	49.18

THE TIME AT LAST STEP = 960.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/2	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	960.00	15.17	19.36	24.92	27.84	29.82	30.55	36.12	41.75	42.72	44.12	45.71	47.50	49.18
24	972.00	10.22	15.48	22.36	25.93	28.33	29.17	35.25	41.38	42.42	43.89	45.54	47.45	49.17
48	984.00	10.22	14.76	20.74	23.94	26.28	27.16	34.00	40.89	42.05	43.63	45.38	47.38	49.16
72	996.00	0.32	7.07	15.69	20.14	23.21	24.31	32.30	40.28	41.59	43.33	45.20	47.31	49.15
96	1008.00	0.32	5.70	12.61	16.24	18.88	19.95	29.67	39.39	40.97	42.96	45.00	47.23	49.13
120	1020.00	2.30	6.03	10.86	13.44	15.46	16.43	27.34	38.36	40.18	42.48	44.76	47.14	49.11
144	1032.0	2.30	6.35	9.30	11.44	13.21	14.15	25.70	37.39	39.35	41.92	44.47	47.04	49.09
168	1044.0	11.21	11.41	11.92	12.44	13.27	13.98	25.15	36.59	38.58	41.33	44.14	46.93	49.07
192	1056.0	11.21	11.82	12.76	13.44	14.30	14.98	25.42	36.12	38.00	40.77	43.77	46.79	49.04
216	1068.00	17.15	16.37	15.61	15.49	15.88	16.42	25.96	35.80	37.57	40.30	43.40	46.65	49.01
240	1080.00	17.15	16.96	16.87	17.02	17.50	18.02	26.72	35.67	37.30	39.92	43.05	46.43	48.97
264	1092.0	31.01	27.17	22.59	20.70	20.13	20.36	27.85	35.66	37.13	39.62	42.73	46.32	48.94
288	1104.0	31.01	29.27	24.80	23.40	22.92	23.11	29.37	35.89	37.14	39.42	42.45	46.15	48.89
312	1116.0	30.02	29.24	25.34	25.00	24.72	24.92	30.44	36.15	37.25	39.32	42.22	45.98	48.85
336	1128.0	30.02	29.62	26.82	26.10	25.93	26.13	31.17	36.38	37.39	39.28	42.04	45.82	48.80
360	1140.0	37.05	33.62	29.18	27.58	27.07	27.19	31.81	36.60	37.52	39.29	41.90	45.66	48.75
384	1152.0	37.05	34.20	30.44	28.91	28.32	28.39	32.53	36.83	37.67	39.31	41.80	45.52	48.70
408	1164.0	43.11	36.70	33.23	30.33	29.45	29.46	33.20	37.08	37.84	39.36	41.73	45.38	48.65
432	1176.00	43.11	39.55	34.74	31.95	30.76	30.66	33.94	37.34	38.03	39.44	41.68	45.27	48.60
456	1188.0	40.98	38.00	35.20	33.61	32.44	31.97	34.73	37.64	38.24	39.53	41.66	45.16	48.56
480	1200.0	40.98	39.56	36.70	35.81	35.37	35.34	36.69	38.18	38.57	39.67	41.66	45.07	48.51

THE TIME AT LAST STEP = 1200.00 HOURS (TIME INCREMENT = 0.50 HOURS)

T/2	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	1200.00	40.08	30.56	36.70	35.81	35.37	35.34	36.69	38.18	38.57	39.67	41.66	45.07	48.51
24	1212.00	29.03	30.92	33.22	34.34	35.03	35.26	36.95	38.61	38.95	39.88	41.68	44.99	48.47
48	1224.00	29.03	30.34	32.00	32.87	33.48	33.74	36.22	38.69	39.15	40.07	41.74	44.92	48.43
72	1236.00	21.11	24.96	29.96	31.73	32.32	32.60	35.62	38.67	39.22	40.19	41.81	44.87	48.40
96	1248.00	21.11	24.36	28.66	30.69	31.72	32.00	35.28	38.61	39.21	40.26	41.87	44.83	48.37
120	1260.00	24.08	25.98	28.57	30.07	31.18	31.60	35.06	38.57	39.20	40.28	41.91	44.80	48.34
144	1272.00	24.03	25.90	28.37	29.71	30.72	31.13	34.79	38.50	39.17	40.29	41.93	44.78	48.32
168	1284.00	11.21	17.07	24.60	28.14	29.99	30.56	34.46	38.41	39.12	40.28	41.94	44.76	48.30
192	1296.00	11.21	16.12	22.60	26.00	28.31	29.07	33.64	38.23	39.02	40.25	41.94	44.75	48.28
216	1308.00	14.18	17.57	22.09	24.58	26.44	27.14	32.51	37.91	38.82	40.17	41.92	44.73	48.26
240	1320.00	14.18	17.19	21.17	23.23	24.87	25.52	31.49	37.52	38.55	40.04	41.89	44.71	48.25
264	1332.00	14.18	16.80	20.25	22.03	23.43	24.12	30.58	37.12	38.24	39.86	41.82	44.69	48.24
288	1344.00	14.18	16.45	19.43	21.04	22.31	22.92	29.77	36.72	37.91	39.65	41.73	44.67	48.23
312	1356.00	5.27	9.75	15.42	18.30	20.31	21.12	28.69	36.28	37.57	39.42	41.62	44.64	48.21
336	1368.00	5.27	9.80	13.34	15.73	17.53	18.34	26.97	35.66	37.13	39.15	41.48	44.60	48.20
360	1380.00	16.16	16.05	16.14	16.44	17.04	17.59	26.22	35.07	36.61	38.82	41.32	44.55	48.19
384	1392.00	16.16	16.44	16.92	17.33	17.93	18.44	26.49	34.76	36.23	38.46	41.13	44.49	48.18
408	1404.00	20.12	19.49	18.84	18.74	19.03	19.45	26.91	34.58	35.97	38.20	40.93	44.43	48.16
432	1416.00	20.12	19.91	19.75	19.82	20.18	20.58	27.46	34.53	35.82	37.98	40.73	44.35	48.15
456	1428.00	20.12	20.18	20.33	20.55	20.97	21.37	27.65	34.52	35.74	37.81	40.56	44.27	48.13
480	1440.00	20.12	20.36	20.74	21.06	21.53	21.92	28.14	34.51	35.69	37.69	40.40	44.18	48.11

THE TIME AT LAST STEP = 1440.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/2	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	1440.0	20.12	20.36	20.74	21.06	21.53	21.92	28.14	34.51	35.69	37.69	40.40	44.18	48.11
24	1452.0	14.18	16.27	18.93	20.30	21.33	21.85	28.11	34.49	35.64	37.59	40.27	44.09	48.09
48	1464.0	14.18	15.93	18.23	19.48	20.51	21.05	27.64	34.35	35.54	37.50	40.15	44.01	48.06
72	1476.0	14.18	15.72	17.75	18.88	19.84	20.38	27.21	34.15	35.40	37.39	40.04	43.92	48.04
96	1488.0	14.18	15.56	17.39	18.43	19.34	19.88	26.85	33.96	35.22	37.25	39.93	43.84	48.01
120	1500.0	22.10	21.11	20.02	19.73	19.92	20.29	26.94	33.81	35.06	37.11	39.82	43.76	47.99
144	1512.0	22.10	21.60	21.04	20.91	21.12	21.45	27.54	33.82	34.98	36.99	39.71	43.68	47.96
168	1524.0	28.04	26.04	23.59	22.67	22.47	22.69	28.19	33.90	34.98	36.90	39.60	43.60	47.93
192	1536.0	28.04	26.61	24.80	24.08	23.91	24.11	29.00	34.08	35.05	36.87	39.51	43.53	47.91
216	1548.0	31.01	28.99	26.43	25.43	25.13	25.28	29.70	34.29	35.18	36.88	39.44	43.45	47.88
240	1560.0	31.01	29.42	27.37	26.52	26.25	26.38	30.38	34.57	35.33	36.93	39.40	43.38	47.85
264	1572.0	27.03	29.39	27.53	27.14	27.05	27.21	30.92	34.76	35.51	37.00	39.38	43.32	47.83
288	1584.0	27.03	29.50	27.81	27.56	27.57	27.74	31.30	34.96	35.68	37.10	39.38	43.27	47.80
312	1596.0	32.00	30.60	28.80	28.17	28.05	28.20	31.62	35.15	35.83	37.19	39.39	43.22	47.78
336	1608.0	32.00	30.86	29.37	28.78	28.62	28.74	31.98	35.33	35.99	37.29	39.42	43.18	47.76
360	1620.0	27.05	27.76	28.65	28.89	29.01	29.18	32.30	35.52	36.14	37.40	39.46	43.15	47.74
384	1632.0	27.05	27.63	28.40	28.78	29.10	29.32	32.45	35.67	36.28	37.50	39.50	43.13	47.72
408	1644.0	23.04	29.24	28.55	28.80	29.11	29.34	32.52	35.78	36.40	37.60	39.55	43.11	47.71
432	1656.0	23.04	29.28	28.62	28.86	29.16	29.38	32.59	35.88	36.50	37.69	39.60	43.10	47.69
456	1668.0	35.03	32.93	30.23	29.44	29.37	29.52	32.70	35.97	36.59	37.77	39.66	43.10	47.63
480	1680.0	35.03	32.31	31.04	30.16	29.88	29.97	32.98	36.09	36.69	37.85	39.70	43.10	47.67

THE TIME AT LAST STEP = 1680.00 HOURS (TIME INCREMENT = 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	1680.00	35.03	33.31	31.04	30.16	29.88	29.97	32.98	36.09	36.69	37.85	39.70	43.10	47.67
24	1692.00	43.11	39.22	34.22	31.42	30.57	30.56	33.34	36.24	36.80	37.93	39.75	43.11	47.67
48	1704.00	43.11	40.01	36.00	33.75	31.88	31.61	33.97	36.44	36.95	38.02	39.81	43.12	47.66
72	1716.00	36.04	35.55	34.90	34.58	34.42	34.44	35.62	36.89	37.21	38.15	39.87	43.13	47.66
96	1728.00	36.04	35.73	35.36	35.20	35.15	35.19	36.20	37.28	37.54	38.34	39.95	43.14	47.66
120	1740.00	29.03	30.68	32.63	33.69	34.31	34.52	36.04	37.53	37.82	38.55	40.05	43.17	47.66
144	1752.00	29.03	30.25	31.88	32.51	32.99	33.21	35.38	37.56	37.95	38.73	40.16	43.20	47.66
168	1764.00	13.19	19.63	27.70	31.07	31.96	32.17	34.84	37.52	38.00	38.84	40.27	43.23	47.66
192	1776.0	13.19	19.50	25.43	29.00	30.98	31.55	34.50	37.47	38.00	38.91	40.36	43.27	47.66
216	1788.00	6.26	13.03	21.84	26.38	29.21	30.03	33.69	37.33	37.95	38.95	40.44	43.31	47.67
240	1800.00	6.26	12.02	19.57	23.60	26.43	27.34	32.19	37.00	37.80	38.94	40.50	43.35	47.68
264	1812.00	6.26	11.14	17.49	20.85	23.24	24.10	30.30	36.47	37.49	38.84	40.52	43.39	47.69
288	1824.0	5.26	10.28	15.47	18.19	20.17	20.97	28.38	35.81	37.04	38.65	40.51	43.43	47.70
312	1836.00	-1.66	3.73	10.50	13.75	16.39	17.35	26.21	35.05	36.50	38.37	40.45	43.45	47.71
336	1848.00	1.66	2.43	7.64	10.36	12.41	13.36	23.70	34.09	35.81	38.00	40.33	43.46	47.72
360	1860.00	12.20	11.76	11.50	11.66	12.24	12.85	22.92	33.27	35.07	37.54	40.16	43.46	47.73
384	1872.0	12.20	12.35	12.70	13.07	13.71	14.28	23.46	32.89	34.57	37.09	39.94	43.44	47.73
408	1884.00	20.12	19.43	16.52	15.85	15.87	16.26	24.34	32.72	34.25	36.73	39.70	43.40	47.73
432	1896.00	20.12	19.22	16.21	17.89	18.04	18.40	25.47	32.77	34.14	36.47	39.47	43.35	47.73
456	1908.0	27.05	24.61	21.65	20.50	20.18	20.40	26.53	32.91	34.13	36.31	39.27	43.28	47.73
480	1920.00	27.05	25.36	23.25	22.41	22.13	22.38	27.67	33.16	34.23	36.24	39.11	43.21	47.72

THE TIME AT LAST STEP = 1920.00 HOURS (TIME INCREMENT= 0.50 HOURS)

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T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	1920.00	27.05	25.36	23.25	22.41	22.18	22.38	27.67	33.16	34.23	36.24	39.11	43.21	47.72
24	1932.00	9.23	17.27	18.27	20.64	22.09	22.66	27.99	33.37	34.37	36.23	39.00	43.14	47.71
48	1944.00	9.23	12.34	16.35	18.44	19.96	20.60	26.91	33.26	34.38	36.24	38.92	43.06	47.69
72	1956.00	-1.66	3.82	10.66	14.11	16.46	17.36	25.15	32.90	34.21	36.18	38.86	43.00	47.68
96	1968.0	-1.66	2.44	7.64	10.34	12.34	13.23	22.70	32.20	33.79	36.01	38.78	42.93	47.66
120	1980.00	7.25	8.09	9.36	10.22	11.17	11.86	21.76	31.90	33.39	35.75	38.67	42.87	47.64
144	1992.00	7.25	8.26	9.67	10.56	11.51	12.17	21.84	31.73	33.18	35.52	38.53	42.80	47.62
168	2004.00	8.24	9.06	10.25	11.03	11.90	12.54	21.94	31.57	33.00	35.33	38.38	42.73	47.60
192	2016.00	8.24	9.19	10.52	11.36	12.25	12.88	22.04	31.42	32.83	35.16	38.24	42.66	47.58
216	2028.00	-11.56	-5.36	2.26	6.07	8.72	3.81	20.53	31.24	32.67	35.01	38.11	42.58	47.56
240	2040.0	11.56	-7.05	-1.34	1.65	3.95	5.06	17.92	30.87	32.43	34.84	37.97	42.50	47.54
264	2052.0	0.32	0.78	1.47	2.42	3.45	4.29	17.19	30.39	32.06	34.62	37.83	42.43	47.52
288	2064.0	0.32	1.22	2.56	3.48	4.55	5.36	17.56	30.04	31.95	34.41	37.68	42.34	47.49
312	2076.00	6.26	5.85	5.62	5.78	6.40	7.06	18.31	29.88	31.86	34.27	37.53	42.26	47.47
336	2088.00	6.26	6.49	6.98	7.45	8.13	8.84	19.21	29.85	31.76	34.14	37.40	42.17	47.44
360	2100.00	6.26	6.86	7.78	8.44	9.26	9.91	19.77	29.86	31.68	34.03	37.27	42.09	47.42
384	2112.0	6.26	7.08	8.26	9.03	9.91	10.55	20.10	29.86	31.60	33.93	37.16	42.00	47.39
408	2124.0	-5.62	1.57	3.47	6.07	8.00	8.92	19.34	29.83	31.53	33.84	37.05	41.92	47.36
432	2136.00	-5.62	2.52	1.45	3.60	5.35	6.28	17.30	29.65	31.45	33.75	36.96	41.84	47.33
456	2148.0	-2.65	0.87	1.54	2.35	4.31	5.18	17.20	29.43	31.35	33.65	36.86	41.76	47.31
480	2160.0	-2.65	-0.95	1.36	2.72	4.04	4.99	16.97	29.26	31.23	33.55	36.77	41.69	47.28

THE TIME AT LAST STEP = 2160.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BEY	1	2	3	4	5	6	7	8	9	10	11	12
0	2160.00	-2.65	-0.95	1.36	2.72	4.04	4.90	16.97	29.26	31.23	33.55	36.77	41.69	47.28
24	2172.00	13.19	10.74	8.06	7.10	7.06	7.55	18.16	29.16	31.11	33.44	36.68	41.61	47.25
48	2184.00	13.19	12.05	10.92	10.45	10.65	11.11	20.03	29.24	31.00	33.33	36.58	41.54	47.23
72	2196.00	5.27	6.96	9.12	10.32	11.37	12.01	20.61	29.35	30.92	33.23	36.49	41.47	47.20
96	2208.00	5.27	6.74	8.71	9.83	10.88	11.53	20.36	29.35	30.87	33.15	36.40	41.40	47.17
120	2220.00	5.27	6.63	8.46	9.53	10.55	11.20	20.17	29.30	30.82	33.08	36.32	41.33	47.15
144	2232.00	5.27	6.56	8.31	9.35	10.34	10.99	20.03	29.24	30.76	33.01	36.24	41.26	47.12
168	2244.0	28.04	23.18	17.42	15.07	14.16	14.30	21.57	29.23	30.70	32.94	36.17	41.20	47.10
192	2256.0	28.04	26.85	20.91	19.24	18.57	18.67	23.92	29.43	30.67	32.88	36.10	41.14	47.07
216	2268.00	14.18	15.93	18.06	19.08	19.78	20.15	24.86	29.65	30.68	32.85	36.03	41.08	47.05
240	2280.00	14.18	15.56	17.36	18.33	19.12	19.53	24.60	29.75	30.72	32.83	35.98	41.02	47.03
264	2292.0	10.22	12.51	15.42	16.92	18.03	18.54	24.13	29.78	30.76	32.83	35.94	40.97	47.01
288	2304.00	10.22	12.06	14.45	15.74	16.76	17.28	23.48	29.75	30.79	32.83	35.91	40.92	46.99
312	2316.00	30.02	26.01	21.19	19.28	18.56	18.67	24.07	29.73	30.80	32.84	35.88	40.87	46.96
336	2328.0	30.02	27.2[illegible]	23.65	22.14	21.51	21.56	25.62	29.86	30.82	32.84	35.86	40.83	46.95
360	2340.0	33.01	29.92	25.97	24.34	23.63	23.63	26.75	30.03	30.86	32.84	35.84	40.79	46.93
384	2352.0	33.01	30.53	27.31	25.92	25.25	25.26	27.58	30.21	30.92	32.87	35.83	40.76	46.91
408	2364.00	40.08	35.65	29.87	27.68	26.73	25.62	28.45	30.37	31.00	32.90	35.82	40.72	46.89
432	2376.00	40.08	36.31	31.29	27.18	28.17	28.01	29.24	30.57	31.09	32.95	35.82	40.70	46.88
456	2388.00	23.09	25.59	28.64	29.21	29.02	28.98	29.84	30.75	31.19	33.00	35.83	40.67	46.87
480	2400.00	23.09	24.94	27.35	28.37	28.87	29.01	29.95	30.90	31.29	33.07	35.85	40.66	46.85

THE TIME AT LAST STEP = 2400.00 HOURS (TIME INCREMENT= 0.50 HOURS)

I/2	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	2400.00	23.09	24.34	27.35	28.39	28.87	29.01	29.95	30.90	31.29	33.07	35.85	40.66	46.85
24	2412.00	15.17	19.25	24.49	26.90	28.12	28.44	29.73	31.01	31.40	33.14	35.88	40.64	46.84
48	2424.00	15.17	19.54	22.96	25.21	26.64	27.07	29.08	31.07	31.49	33.21	35.91	40.63	46.83
72	2436.00	22.10	22.86	23.94	24.76	25.48	25.78	28.42	31.09	31.58	33.28	35.95	40.63	46.82
96	2448.00	22.10	22.91	24.00	24.60	25.10	25.34	28.20	31.10	31.65	33.35	35.98	40.62	46.82
120	2460.00	25.07	24.90	24.75	24.81	25.05	25.24	28.15	31.12	31.71	33.41	36.02	40.63	46.81
144	2472.00	25.07	25.04	25.03	25.09	25.27	25.44	28.26	31.16	31.76	33.46	36.06	40.63	46.81
168	2484.00	13.19	14.85	21.44	23.57	24.76	25.15	28.17	31.20	31.82	33.51	36.09	40.64	46.80
192	2496.00	13.19	14.08	19.83	21.76	23.07	23.55	27.38	31.21	31.87	33.56	36.13	40.65	46.80
216	2508.00	12.20	14.87	18.32	20.10	21.35	21.85	26.50	31.17	31.91	33.60	36.16	40.66	46.80
240	2520.00	12.20	14.38	17.22	18.71	19.82	20.33	25.69	31.10	31.93	33.63	36.19	40.67	46.80
264	2532.00	14.18	15.44	17.14	18.09	18.91	19.37	25.15	31.02	31.94	33.66	36.22	40.68	46.80
288	2544.00	14.18	15.33	16.65	17.72	18.48	18.94	24.89	30.95	31.95	33.68	36.25	40.70	46.80
312	2556.00	4.28	8.04	12.73	15.10	16.75	17.43	24.15	30.88	31.94	33.69	36.27	40.71	46.80
336	2568.00	4.28	7.15	10.83	12.76	14.24	14.94	22.81	30.75	31.92	33.69	36.29	40.72	46.81
360	2580.00	6.26	8.04	10.38	11.70	12.84	13.50	21.93	30.54	31.89	33.69	36.30	40.74	46.81
384	2592.00	6.26	7.83	9.91	11.09	12.17	12.82	21.56	30.44	31.84	33.67	36.30	40.75	46.81
408	2604.00	17.15	15.68	14.08	13.55	13.65	14.05	22.36	30.34	31.78	33.64	36.30	40.76	46.82
432	2616.00	17.15	16.46	15.73	15.55	15.76	15.14	23.14	30.36	31.72	33.60	36.29	40.77	46.82
456	2628.00	33.01	22.23	22.47	20.92	19.07	18.12	24.43	30.43	31.58	33.57	36.28	40.77	46.82
480	2640.00	33.01	20.52	25.06	23.19	22.37	22.37	26.39	30.60	31.66	33.54	36.27	40.78	46.82

THE TIME AT LAST STEP = 2640.00 HOURS (TIME INCREMENT= 0.50 HOURS)

I/Z	ACC TIME	RDY	1	2	3	4	5	6	7	8	9	10	11	12
0	2640.00	33.01	29.52	25.06	23.19	22.37	22.37	26.39	30.60	31.66	33.54	36.27	40.78	46.82
24	2652.00	39.07	34.35	28.24	25.83	24.78	24.69	27.66	30.79	31.68	33.53	36.25	40.78	46.83
48	2664.00	39.07	35.14	29.95	27.78	26.75	26.63	28.74	30.98	31.71	33.53	36.25	40.78	46.83
72	2676.00	39.07	35.66	31.10	29.15	28.20	28.06	29.56	31.15	31.76	33.55	36.24	40.78	46.83
96	2688.00	39.07	36.03	31.96	30.18	29.23	29.15	30.20	31.32	31.83	33.59	36.25	40.78	46.83
120	2700.00	16.16	21.29	27.68	29.59	29.81	29.84	30.64	31.47	31.91	33.63	36.26	40.78	46.83
144	2712.00	16.16	20.12	25.27	27.74	29.04	29.37	30.48	31.59	31.99	33.68	36.28	40.78	46.83
168	2724.00	-1.66	7.02	18.01	23.52	26.72	27.52	29.66	31.72	32.39	33.83	36.32	40.79	46.84
192	2736.0	-1.66	5.20	14.00	18.58	21.70	22.66	27.29	31.79	32.55	33.99	36.38	40.80	46.84
216	2748.0	6.26	9.46	13.64	15.87	17.53	18.22	24.94	31.68	32.58	34.09	36.45	40.81	46.84
240	2760.00	6.26	9.86	12.20	13.97	15.35	16.02	23.72	31.50	32.49	34.13	36.52	40.83	46.84
264	2772.00	18.14	17.05	15.91	15.60	15.81	16.20	23.63	31.29	32.36	34.10	36.56	40.85	46.85
288	2784.00	18.14	17.68	17.21	17.14	17.40	17.77	24.37	31.17	32.25	34.05	36.58	40.87	46.85
312	2796.00	16.16	16.61	17.25	17.68	18.19	18.60	24.78	31.11	32.17	34.00	36.58	40.89	46.85
336	2808.00	16.16	16.69	17.45	17.95	18.50	18.91	24.92	31.07	32.13	33.96	36.57	40.91	46.86
360	2820.0	1.31	5.98	11.75	14.63	16.57	17.33	24.18	31.02	32.09	33.93	36.56	40.92	46.86
384	2832.00	1.31	4.79	9.22	11.52	13.24	14.02	22.41	30.86	32.00	33.89	36.54	40.93	46.87
408	2844.00	-3.64	0.38	5.43	8.04	9.98	10.88	20.72	30.62	31.97	33.85	36.53	40.93	46.87
432	2856.0	-3.64	-0.55	3.41	5.54	7.26	8.16	19.19	30.34	31.91	33.81	36.51	40.94	46.88
456	2868.00	15.17	12.80	10.21	9.29	9.26	9.72	19.73	30.11	31.83	33.76	36.49	40.94	46.88
480	2880.00	15.17	14.03	12.79	12.41	12.57	13.00	21.41	30.10	31.73	33.70	36.46	40.94	46.88

THE TIME AT LAST STEP = 2880.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	2880.00	15.17	14.03	12.79	12.41	12.57	13.00	21.41	30.10	31.73	33.70	36.46	40.94	46.88
24	2892.00	25.07	21.89	18.10	16.58	16.07	16.28	23.08	30.13	31.66	33.64	36.43	40.93	46.88
48	2904.00	25.07	23.00	20.47	19.43	19.11	19.29	24.71	30.34	31.62	33.58	36.39	40.93	46.89
72	2916.00	13.19	15.20	17.69	18.90	19.75	20.18	25.30	30.50	31.60	33.55	36.36	40.92	46.89
96	2928.00	13.19	14.79	16.87	17.99	18.89	19.35	24.91	30.56	31.60	33.53	36.33	40.91	46.89
120	2940.00	22.10	20.96	19.66	19.26	19.33	19.60	25.00	30.57	31.61	33.51	36.31	40.90	46.88
144	2952.00	22.10	21.46	20.71	20.48	20.56	20.81	25.64	30.62	31.61	33.51	36.29	40.89	46.88
168	2964.00	41.09	34.89	27.05	24.12	22.91	22.84	26.66	30.70	31.63	33.51	36.28	40.88	46.88
192	2976.00	41.09	36.12	29.59	26.93	25.69	25.54	28.12	30.85	31.66	33.51	36.27	40.87	46.88
216	2988.00	38.06	34.84	30.51	28.54	27.53	27.39	29.16	31.04	31.70	33.53	36.26	40.86	46.88
240	3000.00	38.06	35.18	31.32	29.61	28.75	28.62	29.88	31.21	31.77	33.56	36.27	40.85	46.88
264	3012.00	32.00	31.54	30.83	30.11	29.57	29.49	30.40	31.37	31.84	33.60	36.27	40.85	46.87
288	3024.00	32.00	31.46	30.72	30.28	29.99	29.96	30.72	31.51	31.92	33.65	36.29	40.84	46.87
312	3036.00	35.03	33.46	31.39	30.61	30.30	30.26	30.93	31.63	32.08	33.71	36.31	40.84	46.87
336	3048.00	35.03	33.66	31.82	31.03	30.65	30.60	31.20	31.85	32.49	33.89	36.36	40.84	46.87
360	3060.00	35.03	33.86	32.31	31.42	31.01	30.95	31.69	32.50	32.82	34.09	36.43	40.85	46.87
384	3072.00	35.03	34.00	32.61	31.79	31.38	31.33	32.20	33.12	33.40	34.39	36.54	40.86	46.87
408	3084.00	39.07	37.08	34.54	33.15	32.00	31.81	32.66	33.58	33.84	34.72	36.68	40.88	46.87
432	3096.00	39.07	37.61	35.79	34.89	34.37	34.24	34.15	34.15	34.28	35.04	36.86	40.92	46.87
456	3108.00	35.03	35.08	35.12	35.11	35.09	35.07	34.89	34.72	34.79	35.40	37.05	40.97	46.87
480	3120.00	35.03	35.04	35.06	35.07	35.07	35.07	35.09	35.13	35.21	35.76	37.27	41.03	46.88

THE TIME AT LAST STEP = 3120.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	3120.0	35.03	35.04	35.06	35.07	35.07	35.07	35.09	35.13	35.21	35.76	37.27	41.03	46.88
24	3132.0	35.03	35.04	35.06	35.07	35.08	35.09	35.27	35.46	35.56	36.08	37.49	41.10	46.89
48	3144.0	35.03	35.04	35.07	35.08	35.11	35.13	35.43	35.76	35.87	36.38	37.72	41.18	46.90
72	3156.0	39.07	39.04	36.31	36.22	35.89	35.83	35.91	36.06	36.16	36.65	37.94	41.27	46.92
96	3168.0	39.07	39.43	37.56	37.14	36.90	36.83	36.61	36.44	36.48	36.92	38.15	41.37	46.94
120	3180.0	43.11	41.60	39.75	38.94	38.30	38.14	37.46	36.85	36.83	37.21	38.36	41.47	46.96
144	3192.0	43.11	42.08	40.78	40.12	39.68	39.53	38.41	37.34	37.24	37.51	38.58	41.58	46.99
168	3204.0	32.00	34.14	36.70	37.89	38.53	38.65	38.23	37.70	37.63	37.84	38.80	41.69	47.01
192	3216.0	32.00	33.39	35.11	35.96	36.48	36.62	37.21	37.74	37.83	38.12	39.03	41.81	47.04
216	3228.0	31.01	32.22	33.74	34.51	35.01	35.18	36.45	37.69	37.91	38.32	39.25	41.93	47.08
240	3240.0	31.01	31.88	32.98	33.56	33.98	34.16	35.89	37.62	37.92	38.45	39.44	42.05	47.11
264	3252.0	37.05	35.14	35.09	34.63	34.40	34.50	36.01	37.61	37.93	38.54	39.60	42.17	47.14
288	3264.0	37.05	36.52	35.89	35.61	35.50	35.53	36.62	37.78	38.03	38.63	39.73	42.29	47.18
312	3276.0	40.18	46.4[illegible]	41.96	39.80	38.59	38.31	38.11	38.11	38.22	38.76	39.86	42.40	47.22
336	3288.0	[illegible].18	47.71	44.64	43.09	42.13	41.84	40.25	38.77	38.65	38.97	39.99	42.51	47.25
360	3300.0	33.06	39.43	41.11	41.83	42.15	42.15	40.79	39.36	39.16	39.28	40.15	42.62	47.29
384	3312.0	38.06	38.92	39.36	40.45	40.71	40.74	40.18	39.57	39.49	39.60	40.35	42.73	47.33
408	3324.0	42.10	41.61	41.01	40.73	40.56	40.50	40.10	39.72	39.69	39.85	40.55	42.84	47.37
432	3336.0	42.10	41.76	41.34	41.12	40.97	40.91	40.42	39.94	39.90	40.07	40.75	42.96	47.40
456	3348.0	47.15	45.59	43.69	42.75	42.18	42.01	41.08	40.22	40.14	40.28	40.94	43.08	47.44
480	3360.0	47.15	46.08	44.73	44.04	43.57	43.40	41.39	40.62	40.45	40.51	41.13	43.20	47.48

THE TIME AT LAST STEP = 3360.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	3360.00	47.15	46.08	44.73	44.04	43.57	43.40	41.99	40.62	40.45	40.51	41.13	43.20	47.48
24	3372.00	34.02	36.65	39.79	41.26	42.04	42.18	41.61	40.89	40.77	40.77	41.32	43.32	47.52
48	3384.00	34.02	35.72	37.83	38.88	39.50	39.67	40.28	40.80	40.87	40.99	41.52	43.44	47.56
72	3396.00	30.02	32.23	34.96	36.32	37.16	37.43	39.05	40.60	40.83	41.11	41.69	43.56	47.60
96	3408.00	30.02	31.56	33.51	34.52	35.22	35.49	37.91	40.30	40.68	41.15	41.84	43.68	47.64
120	3420.00	36.04	35.62	35.18	35.05	35.11	35.24	37.62	40.07	40.50	41.12	41.94	43.79	47.68
144	3432.00	36.04	35.88	35.71	35.68	35.76	35.88	37.93	40.04	40.43	41.09	42.02	43.90	47.72
168	3444.00	52.20	47.98	42.90	40.48	39.17	38.91	39.45	40.23	40.47	41.09	42.07	44.00	47.76
192	3456.00	52.20	49.44	46.00	44.30	43.27	42.98	41.84	40.84	40.80	41.19	42.13	44.09	47.80
216	3468.00	61.29	57.02	51.76	49.15	47.55	47.05	44.24	41.61	41.31	41.42	42.22	44.17	47.83
240	3480.00	61.29	59.33	54.59	52.66	51.36	50.86	46.67	42.55	41.99	41.78	42.36	44.25	47.87
264	3492.00	55.23	54.63	53.77	53.21	52.67	52.32	47.89	43.40	42.72	42.24	42.56	44.34	47.90
288	3504.00	55.23	54.62	53.79	53.28	52.78	52.46	48.27	44.00	43.33	42.72	42.81	44.44	47.93
312	3516.0	38.06	41.93	46.54	48.66	49.71	49.81	47.20	44.33	43.79	43.17	43.09	44.55	47.97
336	3528.00	38.06	40.50	43.49	44.94	45.73	45.86	45.08	44.14	43.91	43.49	43.38	44.67	48.00
360	3540.00	52.20	50.14	47.68	46.51	45.84	45.65	44.78	43.99	43.86	43.67	43.63	44.80	48.04
384	3552.00	52.20	50.83	49.10	48.22	47.64	47.42	45.80	44.21	43.98	43.79	43.83	44.93	48.08
408	3564.00	61.29	57.94	53.81	51.76	50.48	50.05	47.28	44.62	44.24	43.97	44.01	45.06	48.12
432	3576.00	61.29	59.95	55.98	54.44	53.37	52.94	49.08	45.25	44.69	44.23	44.20	45.19	48.16
456	3588.00	65.33	62.54	59.04	57.22	55.97	55.45	50.67	45.94	45.22	44.57	44.40	45.32	48.20
480	3600.00	65.33	63.27	60.62	59.19	58.11	57.59	52.14	46.68	45.82	44.98	44.64	45.45	48.24

THE TIME AT LAST STEP = 3600.00 HOURS (TIME INCREMENT= 0.50 HOURS)

T/Z	ACC TIME	BDY	1	2	3	4	5	6	7	8	9	10	11	12
0	3600.00	65.33	63.27	60.62	59.19	58.11	57.59	52.14	46.68	45.82	44.98	44.64	45.45	49.24
24	3612.00	65.33	62.71	61.61	60.43	59.49	58.98	53.20	47.37	46.43	45.42	44.91	45.58	48.28

THE TIME AT LAST STEP = 3612.00 HOURS (TIME INCREMENT= 0.50 HOURS)

EXECUTION TIME 112.6 SECS

APPENDIX B

CALCULATION OF

FREEZING INDEX

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KE( JTE         IBJOB
3JOB
3FTC MAIN

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 THIS PROGRAM COMPUTE FREEZING INDEX FROM GIVEN DAILY TEMPERATURES ***
****************************************************************************

    DIMENSION DAY(365),TEMP(365),ID(36),DD(365),DDC(365),NDAY(365)
    DIMENSION X(100,4),Y(100,4),NDATA(4),XLINE(20),YLINE(20)
    REAL LOW
    INTEGER PERIOD

300 READ(5,9) ID
    READ(5,10) N
    READ(5,11) (DAY(I),TEMP(I), I=1,N)
    WRITE(6,19)
    WRITE(6,9) ID
    WRITE(6,20)

    COMPUTE DEGREE DAYS AND CUMULATING DEGREE DAYS
    DO 99 I=1,N
    DD(I)=TEMP(I)-32.0
 99 NDAY(I)=DAY(I)
    DDC(1)=DD(1)
    DO 100 I=2,N
.00 DDC(I)=DDC(I-1)+DD(I)
    WRITE(6,12) (NDAY(I),TEMP(I),DD(I),DDC(I), I=1,N)

    FIND THE MAXIMUM VALUE IN CUMULATED DEG DAY VS TIME CURVE
    HIGH=0.
    DO 200 I=1,N
    IF(DDC(I).GE.HIGH) GO TO 201
    GO TO 200
201 HIGH=DDC(I)
    IHIGH=I
200 CONTINUE

    FIND THE MINIMUM VALUE IN CUMULATED DEG DAY VS TIME CURVE
    LOW=0.
    DO 300 I=1,N
    IF(DDC(I).LT.LOW) GO TO 301
    GO TO 300
301 LOW=DDC(I)
    ILOW=I
300 CONTINUE

    CALCULATE FREEZING INDEX AND DURATION OF FREEZING PERIOD
    FI=HIGH-LOW
```

```
      PERIOD=ILOW-IHIGH+1
      WRITE(6,13) HIGH,LOW,FI,PERIOD

    9 FORMAT(18A4)
   10 FORMAT(I5)
   11 FORMAT(10X,2F10.4)
   12 FORMAT(I8,6XF5.1,8XF6.1,14XF8.1)
   13 FORMAT(///10X31HMAXIMUM CUMULATED DEGREE DAYS =,F7.1
     1          /10X31HMINIMUM CUMULATED DEGREE DAYS =,F7.1
     2         //10X16HFREEZING INDEX =,F7.1
     3          /29HDURATION OF FREEZING PERIOD =,I5,///)
   19 FORMAT(1H1)
   20 FORMAT(//5X3HDAY,3X11HTEMPERATURE,3X11HDEGREE DAYS,
     1  3X21HCUMULATED DEGREE DAYS//)

      GO TO 800
      END
```

THE FOLLOWING AVE. DAILY TEMPERATURE WERE RECORDED AT
EST LAFAYETTE, INDIANA (PURDUE), NOV. 1962 - MARCH 1963

DAY	TEMPERATURE	DEGREE DAYS	CUMULATED DEGREE DAYS
1	40.0	8.0	8.0
2	41.0	9.0	17.0
3	40.0	8.0	25.0
4	41.0	9.0	34.0
5	35.0	3.0	37.0
6	38.0	6.0	43.0
7	39.0	7.0	50.0
8	44.0	12.0	62.0
9	37.0	5.0	67.0
10	40.0	8.0	75.0
11	38.0	6.0	81.0
12	38.0	6.0	87.0
13	39.0	7.0	94.0
14	42.0	10.0	104.0
15	44.0	12.0	116.0
16	50.0	18.0	134.0
17	44.0	12.0	146.0
18	35.0	3.0	149.0
19	36.0	4.0	153.0
20	35.0	3.0	156.0
21	41.0	9.0	165.0
22	41.0	9.0	174.0
23	31.0	-1.0	173.0
24	38.0	6.0	179.0
25	35.0	3.0	182.0
26	36.0	4.0	186.0
27	38.0	6.0	192.0
28	39.0	7.0	199.0
29	41.0	9.0	208.0
30	46.0	14.0	222.0
31	46.0	14.0	236.0
32	44.0	12.0	248.0
33	44.0	12.0	260.0
34	42.0	10.0	270.0
35	44.0	12.0	282.0
36	29.0	-3.0	279.0
37	23.0	-9.0	270.0
38	25.0	-7.0	263.0
39	26.0	-6.0	257.0
40	15.0	-17.0	240.0
41	10.0	-22.0	218.0
42	0.	-32.0	186.0
43	2.0	-30.0	156.0
44	11.0	-21.0	135.0
45	17.0	-15.0	120.0
46	31.0	-1.0	119.0
47	30.0	-2.0	117.0
48	37.0	5.0	122.0
49	43.0	11.0	133.0
50	40.0	8.0	141.0
51	29.0	-3.0	138.0
52	21.0	-11.0	127.0
53	24.0	-8.0	119.0

54	11.0	-21.0	98.0
55	14.0	-18.0	80.0
56	14.0	-18.0	62.0
57	5.0	-27.0	35.0
58	16.0	-16.0	19.0
59	20.0	-12.0	7.0
60	20.0	-12.0	-5.0
61	14.0	-18.0	-23.0
62	14.0	-18.0	-41.0
63	22.0	-10.0	-51.0
64	28.0	-4.0	-55.0
65	31.0	-1.0	-56.0
66	29.0	-3.0	-59.0
67	32.0	-0.	-59.0
68	27.0	-5.0	-64.0
69	28.0	-4.0	-68.0
70	35.0	3.0	-65.0
71	43.0	11.0	-54.0
72	36.0	4.0	-50.0
73	29.0	-3.0	-53.0
74	13.0	-19.0	-72.0
75	6.0	-26.0	-98.0
76	6.0	-26.0	-124.0
77	-2.0	-34.0	-158.0
78	12.0	-20.0	-178.0
79	20.0	-12.0	-190.0
80	27.0	-5.0	-195.0
81	9.0	-23.0	-218.0
82	-2.0	-34.0	-252.0
83	7.0	-25.0	-277.0
84	8.0	-24.0	-301.0
85	-12.0	-44.0	-345.0
86	0.	-32.0	-377.0
87	6.0	-26.0	-403.0
88	6.0	-26.0	-429.0
89	-6.0	-38.0	-467.0
90	-3.0	-35.0	-502.0
91	13.0	-19.0	-521.0
92	5.0	-27.0	-548.0
93	5.0	-27.0	-575.0
94	28.0	-4.0	-579.0
95	14.0	-18.0	-597.0
96	10.0	-22.0	-619.0
97	30.0	-2.0	-621.0
98	33.0	1.0	-620.0
99	40.0	8.0	-612.0
100	23.0	-9.0	-621.0
101	15.0	-17.0	-638.0
102	22.0	-10.0	-648.0
103	25.0	-7.0	-655.0
104	13.0	-19.0	-674.0
105	12.0	-20.0	-694.0
106	14.0	-18.0	-712.0
107	4.0	-28.0	-740.0
108	6.0	-26.0	-766.0
109	17.0	-15.0	-781.0
110	33.0	1.0	-780.0
111	39.0	7.0	-773.0
112	39.0	7.0	-766.0
113	16.0	-16.0	-782.0
114	-2.0	-34.0	-816.0

115	6.0	-26.0	-842.0
116	18.0	-14.0	-856.0
117	16.0	-16.0	-872.0
118	1.0	-31.0	-903.0
119	-4.0	-36.0	-939.0
120	15.0	-17.0	-956.0
121	25.0	-7.0	-963.0
122	13.0	-19.0	-982.0
123	22.0	-10.0	-992.0
124	41.0	9.0	-983.0
125	38.0	6.0	-977.0
126	32.0	-0.	-977.0
127	35.0	3.0	-974.0
128	35.0	3.0	-971.0
129	39.0	7.0	-964.0
130	35.0	3.0	-961.0
131	35.0	3.0	-958.0
132	39.0	7.0	-951.0
133	43.0	11.0	-940.0
134	32.0	-0.	-940.0
135	31.0	-1.0	-941.0
136	37.0	5.0	-936.0
137	50.0	18.0	-918.0
138	38.0	6.0	-912.0
139	42.0	10.0	-902.0
140	47.0	15.0	-887.0
141	34.0	2.0	-885.0
142	30.0	-2.0	-887.0
143	36.0	4.0	-883.0
144	52.0	20.0	-863.0
145	61.0	29.0	-834.0
146	55.0	23.0	-811.0
147	38.0	6.0	-805.0
148	52.0	20.0	-785.0
149	61.0	29.0	-756.0
150	65.0	33.0	-723.0
151	65.0	33.0	-690.0

MAXIMUM CUMULATED DEGREE DAYS = 282.0
MINIMUM CUMULATED DEGREE DAYS = -992.0

FREEZING INDEX = 1274.0
ATION OF FREEZING PERIOD = 89

0** EOF READ ON UNIT 00005 --- EXECUTION TERMINATED

COMPILATION 1.0 SEC EXECUTION 7.0 SEC